Delivery Reviews, vol. 107, pp. 228-246 (2016). Progress has also been made in developing additive manufacturing technology for the manufacture of pharmaceutical products. See Goyanes et al., *3D Printing of Medicines: Engineering Novel Oral Devices with Unique Design and Drug Release Characteristics*, Molecular Pharmaceutics, vol. 12, no. 11, pp. 4077-4084 (2015).

[0005] Current additive manufacturing technology is limited, however, by the precision in which three-dimensional printers extrude material. Pharmaceuticals need to be carefully controlled to ensure manufactured products are uniformly shaped and contain a precise and accurate dosage of drug. There continues to be a need to develop precise systems for additive manufacturing processes, including for the use manufacturing pharmaceutical products.

[0006] The disclosures of all publications, patents, patent applications and published patent applications referred to herein are hereby incorporated herein by reference in their entirety.

SUMMARY OF THE INVENTION

[0007] According to a first aspect, there is provided a device for manufacturing a pharmaceutical dosage form by additive manufacturing, including: a material supply system comprising a barrel, a feed channel, and a printing head, the barrel comprising a first heater and configured to melt and pressurize a pharmaceutically acceptable material comprising a drug to convert the pharmaceutically acceptable material to a melted material, the feed channel connecting the barrel to the printing head, and the printing head comprising a nozzle and a second heater, the nozzle comprising a tapered inner surface and an extrusion port configured to dispense the melted material, and the second heater configured to heat the melted material in the printing head to a temperature above a temperature of the melted material in the feed channel; and a control switch comprising a sealing needle operable in an open position and a closed position, the sealing needle extending through a portion of the feed channel and comprising a tapered end; wherein the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle, and the second taper angle is the same or smaller than the first taper angle, and wherein the tapered end of the sealing needle pierces the melted material in the printing head, thereby allowing the melted material to flow up, and engages the tapered inner surface of the nozzle to inhibit the melted material flow through the extrusion port when the sealing needle switches to the closed position.

[0008] In some embodiments, the material is non-filamentous. In some embodiments, the material has a viscosity of about 100 Pa·s or more when extruded from the device. In some embodiments, the material has a viscosity of about 400 Pa·s or more when extruded from the device. In some embodiments, the material melts at about 50 ºC to about 400 ºC. In some

embodiments, the material is extruded from the nozzle at a temperature of about 50 ºC to about 400 ºC. In some embodiments the material is extruded from the nozzle at a temperature of about 90 ºC to about 300 ºC.

[0009] In some embodiments, any portion of the sealing needle that contacts the material is free of protrusions.

[0010] In some embodiments, the pressure sensor is connected to a computer system that operates the material supply system to pressurize the material to a desired pressure in response to the pressure reported by the pressure sensor. In some embodiments, the pressure of the material is within about 0.05 MPa of the desired pressure. In some embodiments, the material supply system comprises a piston and a barrel connected to the feed channel, and wherein the piston is operated to control pressure of the material within the barrel. In some embodiments, the piston is operated using a stepper motor. In some embodiments, the pressure sensor is positioned proximal to the nozzle.

[0011] In some embodiments, the tapered end of the sealing needle comprises a pointed tip. In some embodiments, the tapered end of the sealing needle is frustoconical. In some embodiments, the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle; and wherein the second taper angle is the same or smaller than the first taper angle. In some embodiments, the second taper angle is about 60º or less. In some embodiments, the second taper angle is about 45º or less. In some embodiments, the ratio of the first taper angle to the second taper angle is about 1:1 to about 4:1.

[0012] In some embodiments, the extrusion port has a diameter of about 0.1 mm to about 1 mm. In some embodiments, the tapered end has a largest diameter of about 0.2 mm to about 3.0 mm. In some embodiments, the extrusion port has a diameter and the tapered end has a largest diameter, and the ratio of the largest diameter of the tapered end to the diameter of the extrusion port is about 1:0.8 to about 1:0.1.

[0013] In some embodiments, the control switch comprises an actuator that positions the sealing needle in the open position or the closed position. In some embodiments, the actuator is a pneumatic actuator. In some embodiments, the actuator is a mechanical actuator. In some embodiments, the actuator is an electric motor actuator. In some embodiments, the electric motor actuator is a linear stepper motor actuator.

[0014] In some embodiments, the sealing needle passes through a gasket fixed in position relative to the nozzle, wherein the gasket seals the feed channel.

[0015] In some embodiments, the material supply system comprises one or more heaters configured to melt the material. In some embodiments, the material supply system comprises one or more temperature sensors configured to detect the temperature of the melted material. In some embodiments, the one or more temperature sensors are connected to a computer system that

operates the one or more heaters in response to a temperature reported by the one or more temperature sensors.

[0016] In some embodiments, the tapered end of the sealing needle or the tapered inner surface of the nozzle comprises a flexible pad or liner.

[0017] In some embodiments, the device further comprises a computer system comprising one or more processors and a computer readable memory, wherein the computer system is configured to operate the device. In some embodiments, the computer readable memory comprises instructions for printing a product using the device. In some embodiments, the computer readable memory comprises instructions for controlling the pressure of the material in response to a pressure detected by the pressure sensor. In some embodiments, the computer readable memory comprises instructions for controlling the temperature of the material in response to a temperature detected by the temperature sensor. In some embodiments, the computer readable memory comprises instructions for positioning the sealing needle based on the instructions for printing the product. In some embodiments, the instructions for positioning the sealing needle comprise instructions for selecting an opening distance of the sealing needle based on a desired flow rate of the material from the extrusion port.

[0018] According to a second aspect, there is provided an additive manufacturing system including a plurality of devices for depositing one or more pharmaceutically acceptable materials by additive manufacturing, wherein at least one of the devices is the device of the first aspect.

In some embodiments, the system comprises a first device from the plurality of devices loaded with a first material, and a second device from the plurality of devices loaded with a second material, wherein the first material and the second material are different. In some embodiment, the control switch of each device from the plurality of devices is different. In some embodiment, the control switch of each device from the plurality of devices is the same. In some embodiments, the system comprises a computer system comprising one or more processors and a computer readable memory, wherein the computer system is configured to operate the system. In some embodiments, the computer readable memory comprises instructions for printing a product using the system. In some embodiments, the computer readable memory comprises instructions for controlling the pressure of the material in each material supply system in response to a pressure detected by the pressure sensor in the corresponding material supply system. In some embodiments, the computer readable memory comprises instructions for controlling the temperature of the material in each material supply system in response to a temperature detected by the temperature sensor in the corresponding material supply system. In some embodiments, the computer readable memory comprises instructions for positioning the sealing needle based on the instructions for printing the product. In some embodiments, the

instructions for positioning the sealing needle comprise instructions for selecting an opening distance of the sealing needle based on a desired flow rate of the material from the extrusion port. In some embodiments, at least two of the devices from the plurality of devices comprise: a material supply system configured to melt and pressurize the material, comprising a feed channel connected to a printing head comprising a nozzle, the nozzle comprising a tapered inner surface and an extrusion port configured to dispense the material; a pressure sensor configured to detect a pressure of the material within the nozzle or the feed channel proximal to the nozzle; and a control switch comprising a sealing needle operable in an open position and a closed position, the sealing needle extending through a portion of the feed channel and comprising a tapered end; and wherein the tapered end of the sealing needle engages the tapered inner surface of the nozzle to inhibit material flow through the nozzle when the sealing needle is in the closed position. In some embodiments, the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle; and wherein the second taper angle is the same or smaller than the first taper angle. In some embodiments, the pressure sensor is positioned proximal to the nozzle.

[0019] Disclosed herein is a method of manufacturing a product by additive manufacturing, including: melting and pressurizing a material; flowing the material through an extrusion port of a nozzle comprising a tapered inner surface; engaging a tapered end of a sealing needle with the tapered inner surface of the nozzle, thereby sealing the extrusion port and stopping flow of the melted material, wherein the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle, and wherein the second taper angle is the same or smaller than the first taper angle; and withdrawing the tapered end of the sealing needle, thereby resuming flow of the material through the extrusion port.

In some embodiments, the method comprises receiving instructions for manufacturing the product.

[0020] According to a third aspect, there is provided a method of manufacturing a pharmaceutical dosage form by additive manufacturing, including: melting and pressurizing a pharmaceutically acceptable material comprising a drug, wherein the pharmaceutically acceptable material is melted to a first temperature to convert the pharmaceutically acceptable material to a melted material; heating the melted material in a printing head to a second temperature that is above the first temperature; flowing the melted material through an extrusion port of a nozzle of the printing head, wherein the nozzle comprises a tapered inner surface; engaging a tapered end of a sealing needle with the tapered inner surface of the nozzle, thereby sealing the extrusion port and stopping flow of the melted material, wherein the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle, and wherein the second taper angle is the same or smaller than the first taper angle;

and withdrawing the tapered end of the sealing needle, thereby resuming flow of the melted material through the extrusion port.

In some embodiments, the pharmaceutically acceptable material comprises a drug. In some embodiments, the pharmaceutical dosage forma has a desired drug release profile. In some embodiments, the method comprises receiving instructions for manufacturing the pharmaceutical dosage form.

[0021] In some embodiments of the methods described above, the pressure of the material within the nozzle remains approximately constant. In some embodiments, the method comprises controlling the pressure of the material using a feedback system based on the monitored pressure.

[0022] In some embodiments of the methods described above, the material is non-filamentous. In some embodiments, the material has a viscosity of about 100 Pa·s or more.

[0023] In some embodiments of the methods described above, the any portion of the sealing needle that contacts the material is free of protrusions.

[0024] In some embodiments of the methods described above, the temperature of the material within the nozzle remains approximately constant. In some embodiments, the method comprises monitoring the temperature of the material. In some embodiments, the method comprises controlling the temperature of the material using a feedback system based on the monitored temperature.

[0025] In some embodiments of the methods described above, comprising withdrawing the tapered end of the sealing needle to a selected opening distance.

[0026] In some embodiments of the methods described above, the tapered end of the sealing needle comprises a pointed tip. In some embodiments, the tapered end of the sealing needle is frustoconical. In some embodiments, the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle; and wherein the second taper angle is the same or smaller than the first taper angle. In some embodiments, the second taper angle is about 60º or less. In some embodiments, the second taper angle is about 45º or less. In some embodiments, the ratio of the first taper angle to the second taper angle is about 1:1 to about 4:1. In some embodiments, the extrusion port has a diameter of about 0.1 mm to about 1 mm. In some embodiments, the tapered end has a largest diameter of about 0.2 to about 3.0 mm. In some embodiments, the extrusion port has a diameter and the tapered end has a largest diameter, and the ratio of the largest diameter of the tapered end to the diameter of the extrusion port is about 1:0.8 to about 1:0.1.

[0027] Disclosed herein is a method of manufacturing a product by additive manufacturing, including: melting and pressurizing a first material; flowing the first material through a first extrusion port of a first nozzle comprising a tapered inner surface; engaging a tapered end of a first sealing needle with the tapered inner surface of the first nozzle, wherein the tapered inner

surface of the first nozzle has a first taper angle and the tapered end of the first sealing needle has a second taper angle, and wherein the second taper angle is the same or smaller than the first taper angle, thereby sealing the first extrusion port and stopping flow of the melted first material; melting and pressurizing a second material; and withdrawing a tapered end of a second sealing needle from a tapered inner surface of a second nozzle, wherein the tapered inner surface of the second nozzle has a third taper angle and the tapered end of the second sealing needle has a fourth taper angle, and wherein the fourth taper angle is the same or smaller than the third taper angle, thereby initiating flow of the second material through a second extrusion port.

In some embodiments, the method comprises receiving instructions for manufacturing the product.

[0028] According to a fourth aspect, there is provided a method of manufacturing a pharmaceutical dosage form by additive manufacturing, including: melting and pressurizing a first pharmaceutically acceptable material, wherein the first pharmaceutically acceptable material is melted to a first temperature to convert the pharmaceutically acceptable material to a first melted material; heating the first melted material in a first printing head to a second temperature that is above the first temperature; flowing the first melted material through a first extrusion port of a first nozzle comprising a tapered inner surface; engaging a tapered end of a first sealing needle with the tapered inner surface of the first nozzle, wherein the tapered inner surface of the first nozzle has a first taper angle and the tapered end of the first sealing needle has a second taper angle, and wherein the second taper angle is the same or smaller than the first taper angle, thereby sealing the first extrusion port and stopping flow of the first melted material; melting and pressurizing a second pharmaceutically acceptable material, wherein the second pharmaceutically acceptable material is melted to a third temperature to convert the second pharmaceutically acceptable material to a second melted material; heating the second melted material in a second printing head to a fourth temperature that is above the first temperature; and withdrawing a tapered end of a second sealing needle from a tapered inner surface of a second nozzle, wherein the tapered inner surface of the second nozzle has a third taper angle and the tapered end of the second sealing needle has a fourth taper angle, and wherein the fourth taper angle is the same or smaller than the third taper angle, thereby initiating flow of the second melted material through a second extrusion port; wherein the first pharmaceutically acceptable material or the second pharmaceutically acceptable material comprises a drug.

In some embodiments, the first pharmaceutically acceptable material or the second pharmaceutically acceptable material is an erodible material. In some embodiments, the first pharmaceutically acceptable material or the second pharmaceutically acceptable material comprises a drug. In some embodiments, the pharmaceutical dosage form has a desired drug

release profile. In some embodiments, the method further comprises receiving instructions for manufacturing the pharmaceutical dosage form.

[0029] In some embodiments of the methods described above, the method further comprises monitoring pressure of the first material within the first nozzle or proximal to the first nozzle; or monitoring pressure of the second material with the second nozzle or proximal to the second nozzle. In some embodiments, the pressure of the first material within the first nozzle, or the pressure of the second material within the second nozzle, remains approximately constant. In some embodiments, the method comprises controlling the pressure of the first material or the second material using a feedback system based on the monitored pressure.

[0030] In some embodiments of the methods described above, the first material or the second material is non-filamentous.

[0031] In some embodiments of the methods described above, any portion of the first sealing needle that contacts the first material, or any portion of the second sealing needle that contacts the second material, is free of protrusions.

[0032] In some embodiments of the methods described above, the temperature of the first material within the first nozzle, or the temperature of the second material within the second nozzle, remains approximately constant. In some embodiments, the method comprises monitoring the temperature of the first material or the temperature of the second material. In some embodiments, the method comprises controlling the temperature of the first material using a feedback system based on the monitored temperature of the first material, or controlling the temperature of the second material using a feedback system based on the monitored temperature of the second material.

[0033] In some embodiments of the methods described above, comprising withdrawing the tapered end of the second sealing needle to a selected opening distance.

[0034] In some embodiments of the methods described above, the tapered end of the first sealing needle, or the tapered end of the second sealing needle, comprises a pointed tip. In some embodiments of the methods described above, the tapered end of the first sealing needle, or the tapered end of the second sealing needle, is frustoconical.

[0035] In some embodiments of the methods described above, the tapered inner surface of the first nozzle has a first taper angle and the tapered end of the first sealing needle has a second taper angle; and wherein the second taper angle is the same or smaller than the first taper angle; or the tapered inner surface of the second nozzle has a third taper angle and the tapered end of the second sealing needle has a fourth taper angle; and wherein the fourth taper angle is the same or smaller than the third taper angle. In some embodiments, the fourth taper angle is about 60º or less. In some embodiments of the methods described above, the second taper angle or the fourth taper angle is about 45º or less. In some embodiments of the methods described above, the ratio

of the first taper angle to the second taper angle, or the ratio of the third taper angle to the fourth taper angle, is about 1:1 to about 4:1. In some embodiments of the methods described above, the first extrusion port or the second extrusion port has a diameter of about 0.1 mm to about 1 mm. In some embodiments of the methods described above, the tapered end of the first sealing needle or the tapered end of the second sealing needle has a largest diameter of about 0.2 to about 3.0 mm.

[0036] In some embodiments of the methods described above, the first material or the second material has a viscosity of about 100 Pa·s or more.

[0037] In some embodiments of the methods described above, the product or the pharmaceutical dosage form is manufactured in a batch mode. In some embodiments of the methods described above, the product or the pharmaceutical dosage form is manufactured in a continuous mode.

[0038] Also provided herein is the product or the pharmaceutical dosage form made according to any one of the methods described above.

BRIEF DESCRIPTION OF THE FIGURES

[0039] FIG. 1 illustrates an exemplary embodiment of a device for depositing a material by additive manufacturing according to the present invention.

[0040] FIG. 2A illustrates a cross-sectional view of an exemplary device for depositing a material by additive manufacturing according to the present invention. FIG. 2B illustrates a zoomed in view of the printing head of the device shown in FIG. 2A, with the sealing needle in the closed position and engaging the inner surface of the nozzle. Although FIG. 2A shows a pneumatic actuator, an electric motor actuator (e.g., a linear stepper motor actuator) can be used. The electric motor actuator can position the sealing needle at an open position between the closed position and the maximum open position, such as at a position with a selected opening distance.

[0041] FIG. 3A shows a tapered end of a sealing needle with a pointed tip. FIG. 3B shows a tapered end of a sealing needle with a frustoconical tip. FIG. 3C shows the taper of the inner surface of the nozzle.

[0042] FIG. 4 illustrates an exploded view of components of the pneumatic actuator that connect to the sealing needle to control the sealing needle.

CLAIMS

1. A device for manufacturing a pharmaceutical dosage form by additive manufacturing, comprising:

a material supply system comprising a barrel, a feed channel, and a printing head, the barrel comprising a first heater and configured to melt and pressurize a pharmaceutically acceptable material comprising a drug to convert the pharmaceutically acceptable material to a melted material, the feed channel connecting the barrel to the printing head, and the printing head comprising a nozzle and a second heater, the nozzle comprising a tapered inner surface and an extrusion port configured to dispense the melted material, and the second heater configured to heat the melted material in the printing head to a temperature above a temperature of the melted material in the feed channel; and

a control switch comprising a sealing needle operable in an open position and a closed position, the sealing needle extending through a portion of the feed channel and comprising a tapered end;

wherein the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle, and the second taper angle is the same or smaller than the first taper angle, and

wherein the tapered end of the sealing needle pierces the melted material in the printing head, thereby allowing the melted material to flow up, and engages the tapered inner surface of the nozzle to inhibit the melted material flow through the extrusion port when the sealing needle switches to the closed position.

2. The device of claim 1, wherein the sealing needle is operable in an open position between a maximum open position and a closed position.

3. The device of claim 1 or 2, wherein the tapered end of the sealing needle comprise a frustoconical tip.

4. The device of claim 1 or 2, wherein the tapered end of the sealing needle comprises a pointed tip.

5. The device of any one of claims 1-4, wherein the melted material has a viscosity of about 100 Pa·s or more when extruded from the device.

6. The device of any one of claims 1-5, wherein the pharmaceutically acceptable material is non-filamentous.

7. The device of any one of claims 1-6, wherein any portion of the sealing needle that contacts the melted material is free of protrusions.

8. The device of any one of claims 1-7, wherein the material supply system comprises a piston, and wherein the piston is operated to control the pressure of the melted material within the barrel.

9. The device of any one of claims 1-8, wherein the melted material is extruded from the nozzle at a temperature higher than a temperature of the melted material within the feed channel.

10. The device of any one of claims 1-9, wherein the control switch comprises an actuator that positions the sealing needle.

11. The device of claim 10, wherein the actuator is a pneumatic actuator or a mechanical actuator.

12. The device of claim 10, wherein the actuator is an electric motor actuator.

13. The device of any one of claims 10-12, wherein the sealing needle passes through a gasket fixed in position relative to the nozzle, wherein the gasket seals the feed channel.

14. The device of any one of claims claim 1-13, wherein the material supply system comprises one or more temperature sensors configured to detect the temperature of the melted material.

15. The device of claim 14, wherein the one or more temperature sensors are connected to a computer system that operates the first heater or the second heater in response to a temperature reported by the one or more temperature sensors.

16. The device of any one of claims 1-15, wherein the tapered end of the sealing needle or the tapered inner surface of the nozzle comprises a flexible pad or liner.

17. The device of any one of claims 1-16, further comprising a computer system comprising one or more processors and a computer readable memory, wherein the computer system is configured to operate the device.

18. The device of claim 17, wherein the computer readable memory comprises instructions for printing the pharmaceutical dosage form using the device.

19. The device of claim 18, wherein the material supply system comprises one or more temperature sensors configured to detect a temperature of the melted material, and wherein the computer readable memory comprises instructions for controlling the temperature of the melted material in response to a temperature detected by the one or more temperature sensors.

20. The device of claim 18 or 19, wherein the computer readable memory comprises instructions for positioning the sealing needle based on the instructions for printing the product.

21. An additive manufacturing system comprising a plurality of devices for depositing one or more pharmaceutically acceptable materials by additive manufacturing, wherein at least one of the devices is the device of any one of claims 1-20.

22. The system of claim 21, wherein the plurality of devices comprises a first device loaded with a first pharmaceutically acceptable material, and a second device loaded with a second pharmaceutically acceptable material, wherein the first pharmaceutically acceptable material and the second pharmaceutically acceptable material are different.

23. The system of claim 21 or 22, further comprising a computer system comprising one or more processors and a computer readable memory, wherein the computer system is configured to operate the system.

24. The system of claim 23, wherein the computer readable memory comprises instructions for printing a product using the system.

25. The system of claim 23 or 24, wherein the material supply system of each device in the plurality of devices comprises one or more temperature sensors configured to detect a temperature of the melted material in the corresponding material supply system, and wherein the computer readable memory comprises instructions for controlling the temperature of the melted material in each material supply system in response to a temperature detected by the one or more temperature sensors in the corresponding material supply system.

26. The system of claim 24 or 25, wherein the computer readable memory comprises instructions for positioning the sealing needle based on the instructions for printing the product.

27. The system of any one of claims 21-26, wherein at least two of the devices from the plurality of devices comprise:

a material supply system configured to melt and pressurize the pharmaceutically acceptable material, comprising a feed channel connected to a printing head comprising a nozzle, the nozzle comprising a tapered inner surface and an extrusion port configured to dispense the pharmaceutically acceptable material; and

a control switch comprising a sealing needle operable in an open position and a closed position, the sealing needle extending through a portion of the feed channel and comprising a tapered end; and

wherein the tapered end of the sealing needle engages the tapered inner surface of the nozzle to inhibit material flow through the nozzle when the sealing needle is in the closed position, and

wherein the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle, and the second taper angle is the same or smaller than the first taper angle.

28. A method of manufacturing a pharmaceutical dosage form by additive manufacturing, comprising:

melting and pressurizing a pharmaceutically acceptable material comprising a drug, wherein the pharmaceutically acceptable material is melted to a first temperature to convert the pharmaceutically acceptable material to a melted material;

heating the melted material in a printing head to a second temperature that is above the first temperature;

flowing the melted material through an extrusion port of a nozzle of the printing head, wherein the nozzle comprises a tapered inner surface;

engaging a tapered end of a sealing needle with the tapered inner surface of the nozzle, thereby sealing the extrusion port and stopping flow of the melted material, wherein the tapered inner surface of the nozzle has a first taper angle and the tapered end of the sealing needle has a second taper angle, and wherein the second taper angle is the same or smaller than the first taper angle; and

withdrawing the tapered end of the sealing needle, thereby resuming flow of the melted material through the extrusion port.

29. The method of claim 28, wherein the pharmaceutical dosage form has a desired drug release profile.

30. The method of claim 28 or 29, comprising receiving instructions for manufacturing the pharmaceutical dosage form.

31. The method of any one of claims 28-30, wherein the tapered end of the sealing needle is withdrawn to a selected open distance between a maximum open position and a closed position.

32. The method of any one of claims 28-31, wherein the tapered end of the sealing needle comprises a frustoconical tip.

33. The method of any one of claims 28-31, wherein the tapered end of the sealing needle comprises a pointed tip.

34. The method of any one of claims 28-33, wherein the melted material has a viscosity of about 100 Pa·s or more when extruded.

35. The method of any one of claims 28-34, wherein any portion of the sealing needle that contacts the melted material is free of protrusions.

36. The method of any one of claims 28-35, comprising controlling a temperature of the melted material using a feedback system based on a monitored temperature.

37. A method of manufacturing a pharmaceutical dosage form by additive manufacturing, comprising:

melting and pressurizing a first pharmaceutically acceptable material, wherein the first pharmaceutically acceptable material is melted to a first temperature to convert the pharmaceutically acceptable material to a first melted material;

heating the first melted material in a first printing head to a second temperature that is above the first temperature;

flowing the first melted material through a first extrusion port of a first nozzle comprising a tapered inner surface;

engaging a tapered end of a first sealing needle with the tapered inner surface of the first nozzle, wherein the tapered inner surface of the first nozzle has a first taper angle and the tapered end of the first sealing needle has a second taper angle, and wherein the second taper angle is the same or smaller than the first taper angle, thereby sealing the first extrusion port and stopping flow of the first melted material;

melting and pressurizing a second pharmaceutically acceptable material, wherein the second pharmaceutically acceptable material is melted to a third temperature to convert the second pharmaceutically acceptable material to a second melted material;

heating the second melted material in a second printing head to a fourth temperature that is above the first temperature; and

withdrawing a tapered end of a second sealing needle from a tapered inner surface of a second nozzle, wherein the tapered inner surface of the second nozzle has a third taper angle and the tapered end of the second sealing needle has a fourth taper angle, and wherein the fourth taper angle is the same or smaller than the third taper angle, thereby initiating flow of the second melted material through a second extrusion port;

wherein the first pharmaceutically acceptable material or the second pharmaceutically acceptable material comprises a drug.

38. The method of claim 37, wherein the first pharmaceutically acceptable material or the second pharmaceutically acceptable material is an erodible material.

39. The method of claim 37 or 38, wherein the pharmaceutical dosage form has a desired drug release profile.

40. The method of any one of claims 37-39, comprising receiving instructions for manufacturing the pharmaceutical dosage form.

41. The method of any one of claims 37-40, wherein the tapered end of the second sealing needle is withdrawn to an open position between a maximum open position and a closed position.

42. The method of any one of claims 37-41, wherein the tapered end of the first sealing needle or the tapered end of the second sealing needle comprises a frustoconical tip.

43. The method of any one of claims 37-41, wherein the tapered end of the first sealing needle or the tapered end of the second sealing needle comprises a pointed tip.

44. The method of any one of claims 37-43, wherein the first melted material or the second melted material has a viscosity of about 100 Pa·s or more when extruded.

45. The method of any one of claims 37-44, wherein any portion of the first sealing needle that contacts the first melted material, or any portion of the second sealing needle that contacts the second melted material, is free of protrusions.

46. The method of any one of claims 37-45, comprising controlling a temperature of the first melted material using a feedback system based on a monitored temperature of the first melted material, or controlling a temperature of the second melted material using a feedback system based on a monitored temperature of the second melted material.

47. The method of any one of claims 37-46, wherein the pharmaceutical dosage form is manufactured in a batch mode.

48. The method of any one of claims 37-46, wherein the pharmaceutical dosage form is manufactured in a continuous mode.