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(54) **INTEGRATED COMPLETION STRING AND METHOD FOR MAKING AND USING**

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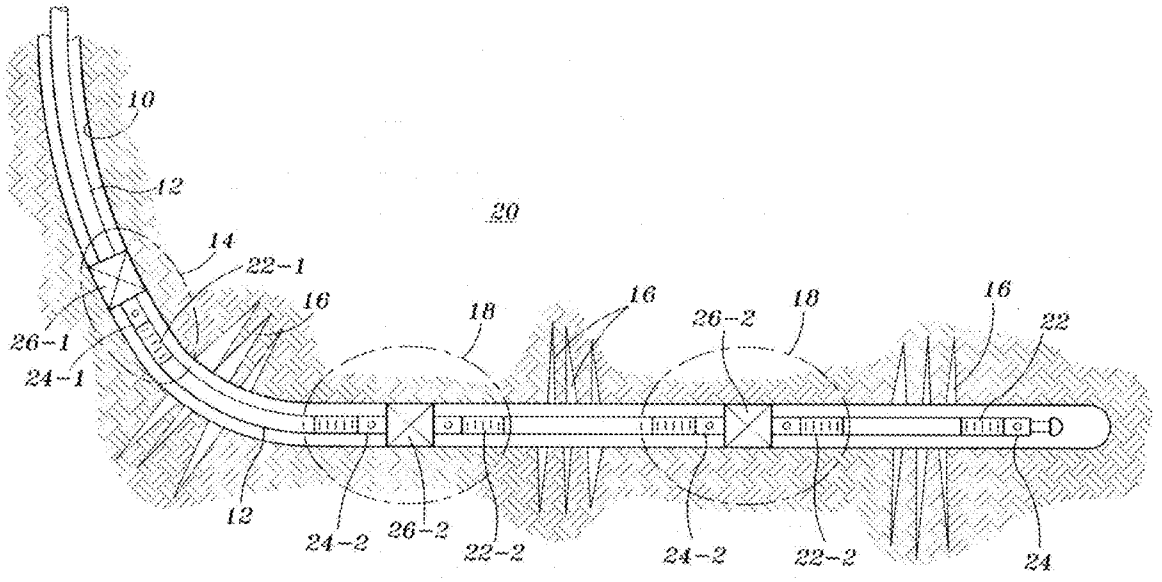
(57) **ABSTRACT**

An integrated apparatus for use in hydrocarbon-producing wells is provided. A device for controlling inflow from a subterranean formation (ICD), a filtration medium for fine particle exclusion and a sealing element (packer) are disposed along a single cylindrical mandrel, preferably an oilfield tubular. The apparatus may be used in a completion method to enhance production rates and increase the total recovery from a subterranean hydrocarbon-producing formation.



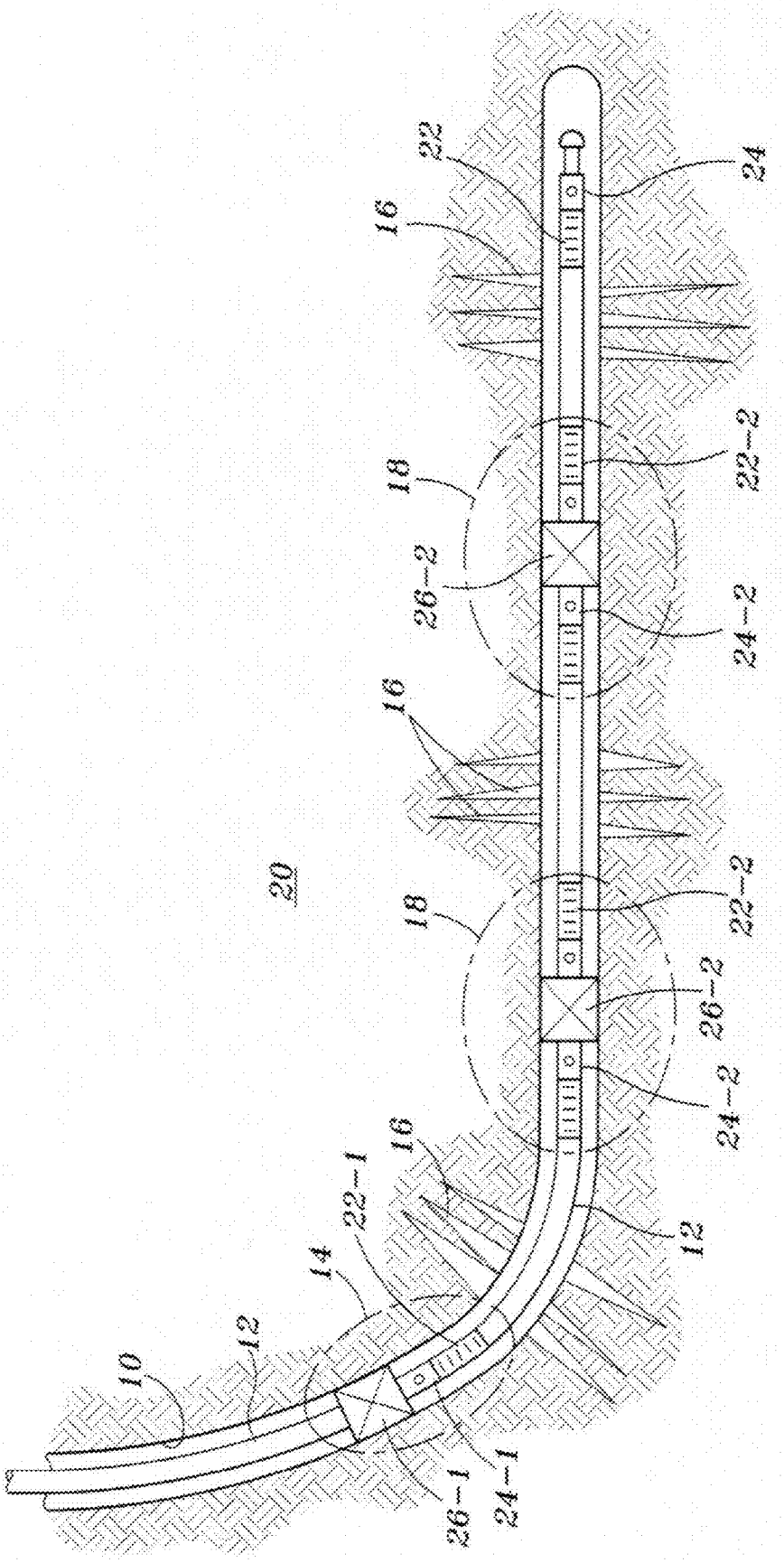


FIG. 1

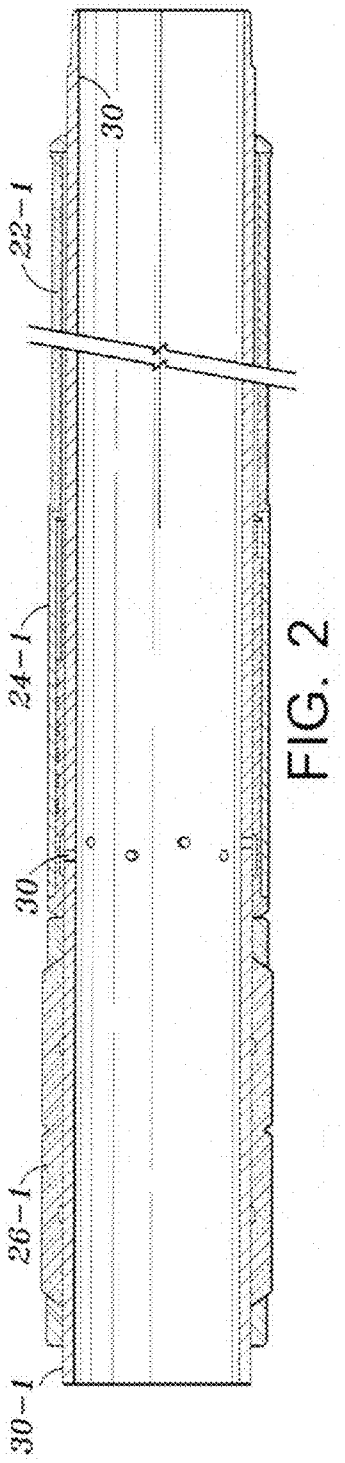


FIG. 2

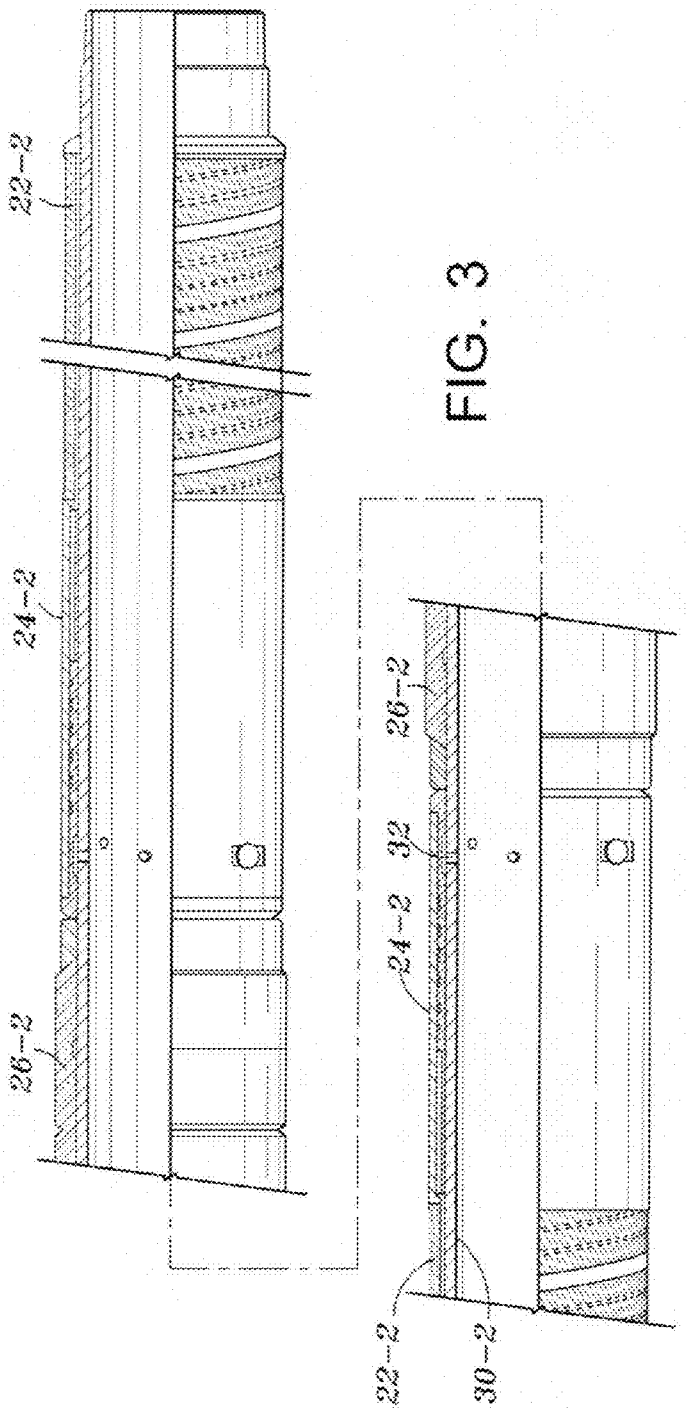


FIG. 3

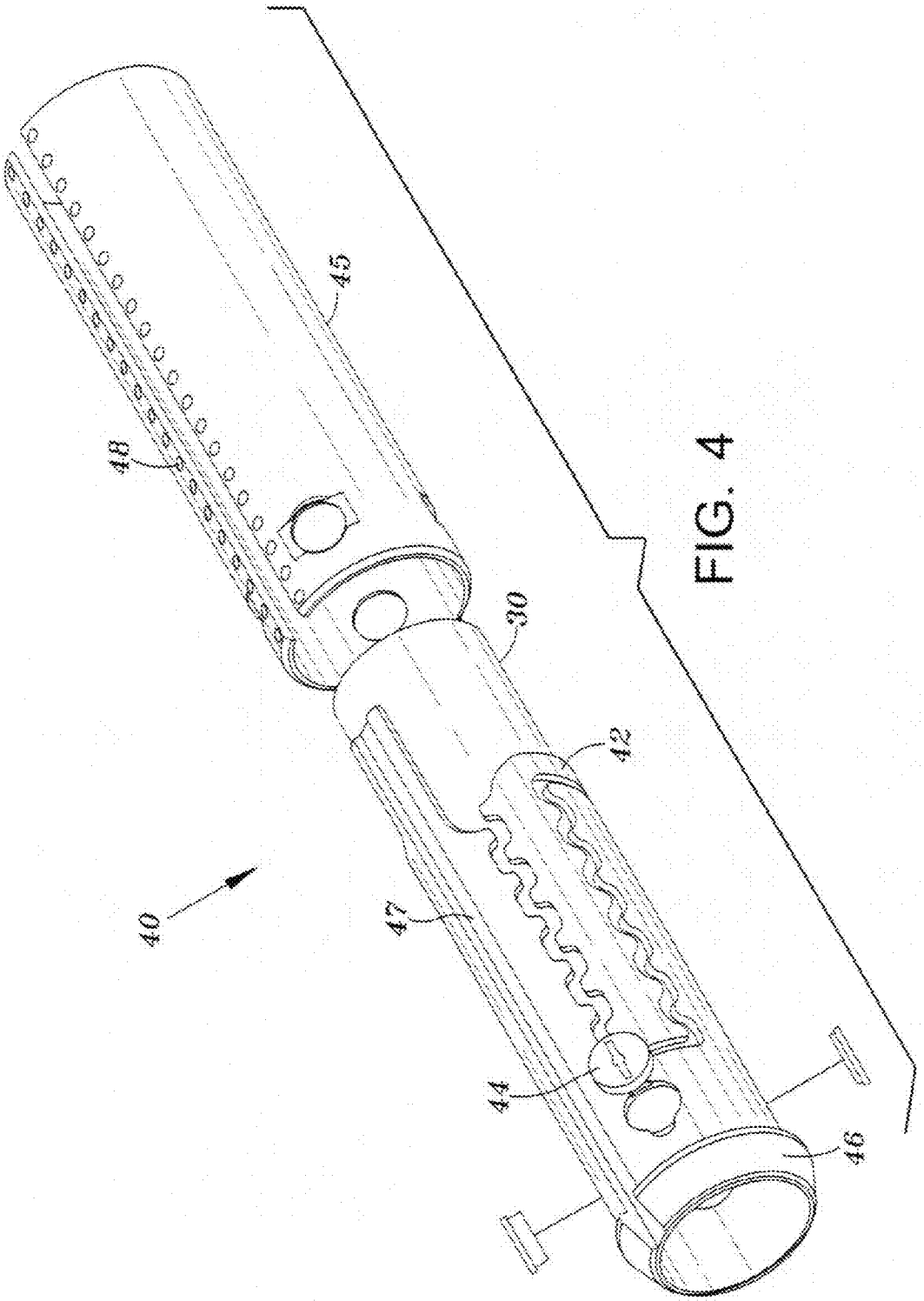


FIG. 4

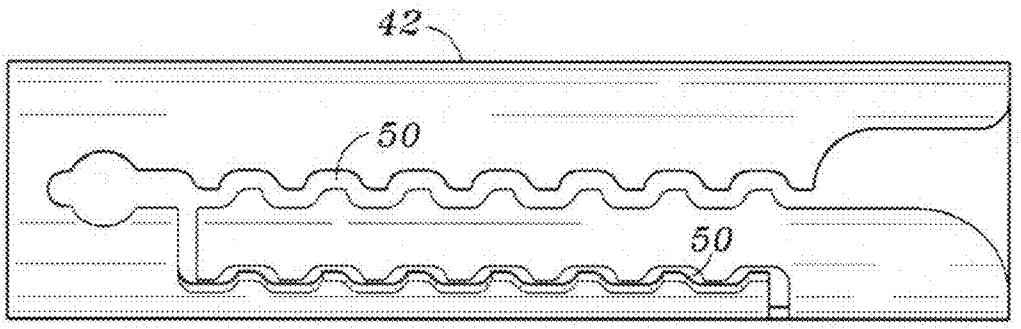


FIG. 5

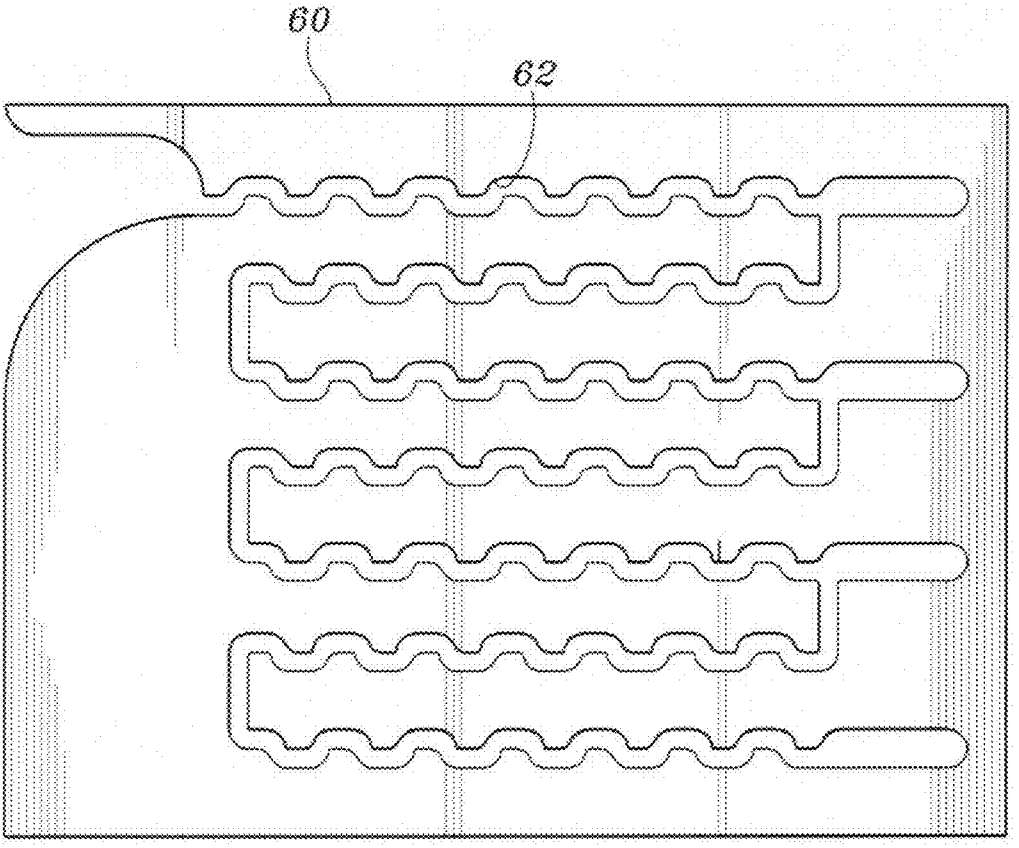


FIG. 6

INTEGRATED COMPLETION STRING AND METHOD FOR MAKING AND USING

BACKGROUND OF INVENTION

[0001] 1. Field of the Invention

[0002] This invention pertains to completion equipment to be used in wells producing hydrocarbons or wells for injection of a fluid. More particularly, method for making integrated apparatus on a single tubular mandrel for isolating flow from different sections of a wellbore, screening out particles in each section and limiting rate of inflow from each section by an Inflow Control Device (ICD) is provided, along with improved methods for making the ICD.

[0003] 2. Description of Related Art

[0004] Packers outside a tubular are commonly used for isolating flow from different sections of a wellbore. Screens are commonly used for preventing particles in produced fluids from entering the tubular. The use of mechanical devices for controlling inflow of fluids into isolated sections of an oil or gas well is known. For example, U.S. Pat. No. 5,435,393 discloses one or more Inflow Control Devices (ICDs) in isolated sections of a wellbore. Flow into the ICDs may be through a screen or filter and flow out is through a port into the tubular or flow conduit that leads to the top of the wellbore. These three devices (packers, screens and ICDs) on separate mandrels are often found operating in combination, connected together by pipe threads or welds.

[0005] What is needed is an improved method for making the ICD and for integrating the three types of devices onto a single integral mandrel, or base pipe, thereby eliminating joints, potential leak paths or failure points and providing a more reliable and less expensive apparatus.

DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** is a sketch of the apparatus disclosed here deployed in a horizontal well.

[0007] FIG. **2** is a cross-sectional view of one embodiment of the disclosed apparatus having a single ICD and a screen along with a packer on a mandrel.

[0008] FIG. **3** is a cross-sectional view of a second embodiment of the disclosed apparatus having two ICDs and two screens along with a packer on a mandrel.

[0009] FIG. **4** is a perspective view of one embodiment of an ICD with a cut-out channel in a sleeve to form a 2-D labyrinth and an outside sleeve to slide over the labyrinth, the outside sleeve forming the outside surface of a channel and being adapted to join to a screen (not shown).

[0010] FIG. **5** is an elevation view of one embodiment of a sleeve having a cut-out 2-D channel.

[0011] FIG. **6** illustrates another embodiment for making an ICD with a cut-out 2-D channel in a flat plate that can be rolled into a cylinder.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0012] FIG. **1** illustrates how the devices disclosed herein may be deployed in a well. A horizontal well is illustrated, but the devices may also be used in a vertical well. Although the well will be described as producing fluids, the descriptions are equally applicable to injection of fluids into the well. Well casing or open hole wellbore **10** penetrates hydrocarbon-producing formation **20**. Tubing **12** extends to the top of wellbore **10**, normally at the surface of the earth or the sea floor. If the wellbore is cased, perforations **16** have been formed through the casing and into formation **20**. Three sets of perforations **16** are shown. If the wellbore is not cased, the perforations are not present. Two embodiments of the device assemblies disclosed herein are shown in FIG. **1**. Type **1** assembly **14** includes packer mechanism **26-1**, ICD **24-1** and screen **22-1**. Type **1** assembly **14** is on a single mandrel that may be inserted in well tubing **12** at a selected location. Type **2** assemblies **18** include packer mechanism **26-2**, two ICDs **24-2** and two screens **22-2**. Type **2** assembly **18** is also on a single mandrel that may be inserted in well tubing **12** at a selected location. Type **2** assembly **18** may be used when two ICDs are preferred to control flow from a single section of the wellbore. This arrangement may be preferred, for example, to minimize the potential effects of plugging of an ICD during the life of a well. Although packers are shown contiguous to ICDs in FIG. **1**, it should be understood that it is not necessary that the ICDs be disposed between the packers and the screens. Screen **22** and ICD **24** may be separately inserted in tubing **12** or may be separately added near the bottom of tubing **12**. They are not a part of an assembly as disclosed herein.

[0013] FIG. **2** illustrates in more detail Type **1** assembly **14**. When in a producing well, fluid flows through screen **22-1** on mandrel **30-1**, into ICD **24-1** on mandrel **30-1** and out of the ICD through ports **31** in mandrel **30-1**. Packer mechanism **26-1** on mandrel **30-1** isolates flow between different sections of a wellbore. When the packer mechanism is set, it forms a seal against an inner surface of the wellbore, which may be casing or open hole. Wellbore fluids enter the screen section, where sand and fine particles are separated from the fluid and remain trapped in the reservoir. This embodiment contains a single ICD-screen combination. Mandrel **30-1** is preferably a single joint of an oil field tubular. Mandrel **30-1** may be longer than a common single joint length. Packer mechanism **26-1** may be adjacent ICD **24-1** or may be displaced from ICD **24-1**, but is on the same mandrel. In another embodiment (not shown), packer element **26-1** may be adjacent screen **22-1** or may be displaced from screen **22-1**.

[0014] FIG. **3** illustrates in more detail Type **2** assembly **18**. When in a producing well, fluid flows through both of screens **22-2** on mandrel **30-2**, into ICDs **24-2** on mandrel **30-2** and out of the ICDs through ports **32** in mandrel **30-2**. Packer mechanism **26-2** on mandrel **30-2** isolates flow between different sections of a wellbore. When the packer mechanism is set, it forms a seal against an inner surface of the wellbore, which may be casing or open hole. Wellbore fluids enter the screen sections, where sand and fine particles are separated from the fluid and remain trapped in the reservoir. This embodiment contains two ICD-screen combinations, all on a single mandrel. Mandrel **30-2** may be longer than a common single joint length. Packer mechanism **26-2** may be adjacent ICDs **24-2** or may be displaced from either or both of the ICDs, but is on the same mandrel.

[0015] Conventional screen structures may be used in the embodiments in FIGS. **2** and **3**. They may be wire-wrapped, have one or more layers of woven wire or be any other structure used in industry. They are available from several service companies. The screen structures are normally placed over a short mandrel extending only the length of the screen, but in the apparatus disclosed herein they are placed over mandrel **30-1** of FIG. **2** or mandrel **30-2** of FIG. **3**, which extends through the screen and a packer and an ICD.

[0016] Conventional packer mechanisms may be used in the embodiments of FIGS. **2** and **3**. They may be mechanically set, hydraulically set or they may be set by swelling in water or oil. They are available from several service companies. The packer mechanisms are normally placed over a short mandrel extending only the length of the packer mechanism, but in the apparatus disclosed herein the packer mechanism is placed over mandrel **30-1** of FIG. **2** or mandrel **30-2** of FIG. **3**, which extends through the packer mechanism and a screen and an ICD. The packer mechanism should slide to a preferred location on the mandrel. The packer mechanism may be joined to the mandrel by welding or any other method normally used when the packer mechanism is assembled with a mandrel. For example, an inflatable packer mechanism may be joined to a mandrel such as **30-1** or **30-2** by curing or adhesively attaching the rubber used in the packer to the mandrel.

[0017] ICDs used in the embodiments of FIGS. **2** and **3** have a structure that can be placed over the mandrel and that will slide to a location to allow fluid exiting the ICD to pass through ports **31** or **32** in the mandrel. The ICD may be joined to a screen before or after it is placed on the mandrel. Preferably, the ICD and screen are joined by welding. This integrated structure and method for making allow a more reliable apparatus and a less expensive manufacturing process. Also, the integrated assembly disclosed herein may be inserted at a selected location in a completion string of tubulars more quickly and with less risk of leaks or damage to equipment. A variety of structures of ICDs are available in industry, including a simple port or straight flow channel from an inflow to an outflow end of the device.

[0018] A preferred structure of ICD **40** is illustrated in FIG. **4**. Sleeve **42** contains a 2-D labyrinth that has been formed in the sleeve using methods to be described below to form the sides of a flow channel from the inflow end to the outflow end along the axis of the sleeve. Plug **44**, placed at a selected location along the flow channel, and may be placed through the sleeve to block or partially block flow through part of the labyrinth. Sleeve **42** may contain a plurality of labyrinths designed to form flow channels. Outer or second sleeve **45**, having spot welds **48**, is sized to slide over the labyrinth or first sleeve and form the outer surface of a flow channel. End cap **46** serves as a stop for one end of sleeve **45** and may be adapted for joining with a packer mechanism. The opposite end of sleeve **45** may be adapted for joining with a screen. A port in mandrel **30** allows fluid exiting the labyrinth to enter mandrel **30**, which is connected to tubing **12**, as shown in FIG. **1**. Exterior channel **47** may be formed to allow passage of electrical or hydraulic lines around the ICD.

[0019] FIG. **5** shows an elevation view of sleeve or cylinder **42**. Channels **50** of a labyrinth are cut through the wall of the sleeve. The channels and adjoining flow areas may be water cut, milled, laser cut or electro-discharge machine (EDM) formed on a section of a cylinder. Cutting completely through the wall of the sleeve, rather than cutting a specified depth in the wall, provides a less expensive manufacturing process for the flow channel of the ICD.

[0020] FIG. **6** illustrates an alternate method for forming sleeve **42**. Flat plate **60** contains channels **62** that may be water cut, milled, laser cut or electro-discharge machine (EDM) formed through the entire thickness of the flat plate, which can be rolled into a cylindrical shape, thereby creating functionally identical geometry as the sleeve section illustrated in FIG. **5**.

[0021] The labyrinth structures illustrated in FIGS. **4**, **5** and **6** may be placed over a mandrel and welded or press fit into location. In one embodiment, this becomes the ICD subassembly, which may be located on and affixed to the longer continuous mandrel which includes an affixed screen and an affixed packer. In other embodiments, the ICD as illustrated in FIGS. **4**, **5** and **6** may be used by itself, or combined with either the packer element and/or a screen section. Alternatively, there may be a mandrel for the ICD that will be slipped over the "longer continuous mandrel."

[0022] Although the present invention has been described with reference to specific details, it is not intended that such details should be regarded as limitations on the scope of the invention, except as and to the extent that they are included in the accompanying claims.

What I claim is:

1. A well completion assembly, comprising:
- a cylindrical mandrel having a wall and a port therethrough;
- a first screen assembly affixed outside the mandrel;
- a packer mechanism affixed outside the mandrel; and
- a first inflow control device affixed outside the mandrel and disposed to receive flow from the screen and deliver flow to the port in the wall of the mandrel.

2. The well completion assembly of claim **1** wherein the cylindrical mandrel is an oilfield tubular.

3. The well completion assembly of claim **1** wherein the first inflow control device includes a labyrinth.

4. The well completion assembly of claim **1** wherein the first screen comprises a layered wire mesh.

5. The well completion assembly of claim **1** wherein the first screen comprises a wire wrapped on the cylindrical mandrel.

6. The well completion assembly of claim **1** wherein the packer mechanism comprises a material formulated to swell in water or oil.

7. The well completion assembly of claim **1** wherein the packer mechanism comprises an inflatable packer.

8. The well completion assembly of claim **1** wherein the packer mechanism comprises a pliable material that is expanded by application of mechanical force.

9. The well completion assembly of claim **1** wherein the first inflow control device is disposed between the first screen and the packer mechanism.

10. The well completion assembly of claim **1** further comprising a second inflow control device affixed outside the mandrel and a second screen affixed outside the mandrel and disposed such that the packer mechanism is disposed between the first inflow control device and the second inflow control device and between the first screen and the second screen.

11. A method for making a well completion assembly, comprising:
- providing a cylindrical mandrel having a wall;
- forming a port through the wall of the mandrel at a selected location;
- providing an inflow control device having an outflow end and affixing the device outside the mandrel and disposed to deliver flow from the outflow end to the port;
- providing a screen and affixing the screen outside the mandrel and in flow communication with the inflow control device so as to deliver flow from the screen to the inflow control device; and
- providing a packer mechanism and affixing the packer mechanism outside the mandrel.

12. The method of claim **11** wherein the method of affixing is welding.

13. The method of claim **11** wherein the inflow control device is affixed between the screen and the packer mechanism.

14. The method of claim **11** wherein the mandrel is a piece of oil field tubular.

15. An inflow control device, comprising:

a mandrel;

a first sleeve having an axis and a wall thickness and adapted to slide over the mandrel and a channel through the wall thickness of the first sleeve from a first location at an inflow end to an outflow end disposed along the axis of the sleeve; and

a second sleeve over the first sleeve, the second sleeve forming an outside wall of a flow channel through the first sleeve and being affixed to the mandrel.

16. The inflow control device of claim **15** wherein the mandrel is a piece of oil field tubular.

17. A method for forming an inflow control device, comprising

providing a mandrel;

providing a first sleeve having an axis and a wall thickness and adapted to slide over the mandrel;

cutting a channel through the wall thickness of the first sleeve from a first location at an inflow end to an outflow end disposed along the axis of the sleeve; and

sliding a second sleeve over the first sleeve, the second sleeve forming an outside wall to the channel through the first sleeve and being sized to slide over the first sleeve; and

affixing the second sleeve to the mandrel.

18. The method of claim **15** wherein the mandrel is a joint of oil field tubular.

19. A method for forming an inflow control device, comprising:

providing a flat piece of material sized for a first sleeve of an inflow control device when rolled into the first sleeve having an inflow end and an outflow end;

cutting a channel through the wall thickness of the flat piece from a first location to a second location such that the channel is disposed from an inflow end to an outflow end along the axis of the first sleeve formed from the flat piece;

rolling the flat piece to form the first sleeve; and

placing a second sleeve over the first sleeve, the second sleeve forming an outside wall to the channel through the first sleeve and being sized to slide over the first sleeve; and

affixing the second sleeve to the mandrel.

20. The method of claim **17** wherein the mandrel is a joint of oil field tubular.

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