



(51) International Patent Classification:
E21B 43/24 (2006.01)

(21) International Application Number:
PCT/US2010/053420

(22) International Filing Date:
20 October 2010 (20.10.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/254,144 22 October 2009 (22.10.2009) US

(71) Applicant (for all designated States except US):
CHEVRON U.S.A. INC. [US/US]; 6001 Bollinger Canyon Road, San Ramon, California 94583 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **SIMS, Jackie, C.** [US/US]; 2023 Gentryside Drive, #312, Houston, Texas 77077 (US).

(74) Agents: **NORTHCUTT, Christopher, D.** et al.; Chevron Corporation, Law Department, P.O. Box 6006, San Ramon, California 94583-0806 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO,

DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: STEAM DISTRIBUTION AND CONDITIONING ASSEMBLY FOR ENHANCED OIL RECOVERY OF VISCOUS OIL

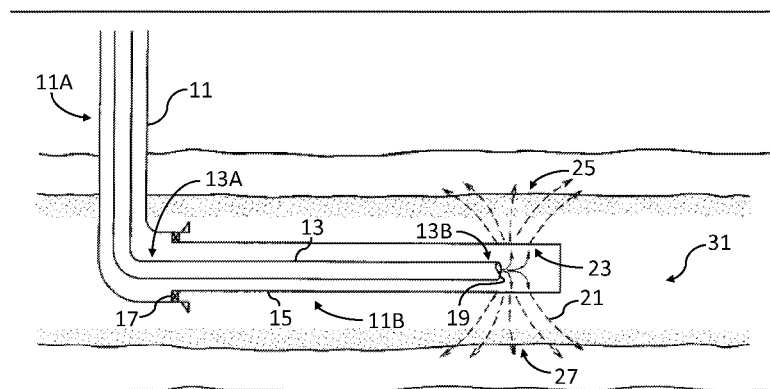


FIG. 1

(57) Abstract: Methods and apparatus for enhanced and improved viscous oil recovery are disclosed. A horizontal well is drilled through the viscous oil formation. A specially designed tubing string includes outlets that deliver steam more uniformly into the entire horizontal extent of the well borehole. Heat from the steam mobilizes and lowers the viscosity of the heavy crude wherein the crude is then produced to the surface via conventional lift arrangements.



**STEAM DISTRIBUTION AND CONDITIONING ASSEMBLY
FOR ENHANCED OIL RECOVERY OF VISCOUS OIL**

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application for patent claims the benefit of United States Provisional Application bearing Serial No. 61/254,144, filed on October 22, 2009, which is incorporated by reference in its entirety.

BACKGROUND

1. Field of the Invention

[0002] This invention relates to oil field production apparatus and techniques, and more particularly, to such apparatus and techniques for use in the production of heavy oil or viscous crude oil.

2. Background of the Invention

[0003] It has been known to produce viscous crude oils in reservoirs by drilling vertical wells into the producing zone and then injecting steam into the producing zone to increase the mobility and reduce the viscosity of the viscous crude. This steam injection has been done in several different ways. In one technique, wells in the reservoir can be cyclically steamed using a process called cyclic steam stimulation (CSS). In this process, steam is injected down a vertical well into the producing zone. The steam is allowed to “soak” in the reservoir for a relatively short period of time to heat the crude oils, thus reducing its viscosity and increasing its mobility. The well is then placed back in production for a relatively longer period of time to extract the heated less viscous crude oil. This cycle is typically repeated until the production becomes unprofitable.

[0004] Another technique which has been used to produce viscous crude reservoirs is to drill vertical wells in a geometrical pattern into the producing zone, such as in a 5-spot or 9-spot pattern. In these geometrical patterns, the wells are placed within the reservoir field, typically in a symmetric fashion, and are designated as either an injection well or a production well based on its position in the pattern. Steam is continuously injected into the producing zone via the injection wells in an attempt to heat the viscous crude oil and drive it to neighboring vertical producing wells in the geometrical array.

[0005] In the initial development of a reservoir of viscous crude these described methods have worked well. Over time however, the steam tends to congregate in the upper portion of the producing zone. This, of course, may cause less heating of the viscous crude in the lower portion of the producing zone. The heavy crude saturated lower portion of the producing zone is not depleted as the high viscosity of the crude prevents its migration to the well bores of the producing wells. Thus large quantities of potentially producible crude oil can otherwise become not recoverable.

[0006] It is known in the art that horizontally-oriented, or horizontal wells can be utilized to help production from the portions of the producing zone, especially the lower portion discussed above, which are typically not depleted after injecting steam with vertical wells. It is desirous in these assemblies to deliver uniformly distributed steam to the producing zone along the entire length of the horizontal section of the well.

[0007] Horizontal steam injection wells are becoming more functional and efficient for heavy oil steam flooding and in many cases the only economic solution to produce some reservoirs. Successful application of horizontal steam injection requires controlled steam distribution along the entire length of the horizontal section. Many devices have been promoted as completion methods to provide this controlled distribution; however, these devices have not been tested and have severe limitations.

[0008] The main limitation is that the proposed equipment can at best provide control for the injection of single phase steam (“100% quality”). The performance of such devices when extracting a portion of a wet steam flow, vapor and liquid, suffers from phase splitting effects. This phase splitting phenomenon relates to the fact that the percent of vapor extracted from the total vapor is different than the percent liquid extracted from the total liquid. For example, if the main flow has a steam quality of seventy-percent (70%), the extracted flow may have a significantly higher or lower quality.

[0009] Many steam flood operations use two-phase steam consisting of both a vapor and a liquid phase. Even for operations injecting single phase, 100% quality steam at the wellhead, heat losses and water holdup can yield varying steam qualities along the subsurface horizontal section. Furthermore, if both phases do not split proportionally within a device, mass distribution is non-uniform and uniform latent heat – a more crucial reservoir performance criteria – is not achieved.

[0010] Most proposed devices extract steam off the main tubing flow through a series of orifices which may or may not feed additional flow restricting mechanisms before delivery to the reservoir. The basis for many of these devices and hopes for

success rely on modified Inflow Control Devices (“ICDs”) operating in a reversed flow direction (“injection mode”). Although not fully tested, such mechanisms do have potential for the distribution of single phase, 100% quality steam. However, in applications utilizing two-phase steam, flow regime effects and different phase velocities cause unknown phase distributions depending on the vapor-water separation within the device. Optimum steam distribution and latent heat delivery requires a device capable of reliably controlling injected steam over a range of qualities of about forty percent (40%) to one-hundred percent (100%).

SUMMARY

[0011] According to an aspect of the present invention, a well assembly is disclosed for injecting steam into a subterranean reservoir. The well assembly includes a string of tubing in fluid communication with a producing zone of a subterranean reservoir. The string of tubing has a substantially vertical section and a substantially horizontal section extending from a lower portion thereof. The substantially horizontal section defines a heel portion at one end and a toe portion at the opposite end. An opening formed on the inner surface of the substantially horizontal section defines an inlet. An opening formed on the outer surface of the substantially horizontal section defines an outlet. A passageway extends between the inlet and the outlet such that steam received by the inlet is delivered to the outlet. A flow conditioning device is positioned in the string of tubing axially closer to the heel portion than the inlet to generate a more homogenous mixture of the vapor and liquid components of the two-phase steam.

[0012] In one or more embodiments, the flow conditioning device is a stator. In one or more embodiments, the flow conditioning device is a plurality of axially spaced stators, which define a conditioning region. In one or more embodiments, the flow conditioning device includes a plurality of vanes extending inwardly from the inner surface of the string of tubing and around the circumference thereof.

[0013] In one or more embodiments, the flow conditioning device is adapted to allow a logging tool to travel therethrough.

[0014] In one or more embodiments, the flow conditioning device is positioned in the string of tubing a length between about four to six times the diameter of the string of tubing upstream of the inlet.

[0015] In one or more embodiments, the flow conditioning device is carried within the string of tubing. In one or more embodiments, the flow conditioning device is positioned between segments of tubing within the substantially horizontal section of the string of tubing.

[0016] In one or more embodiments, the string of tubing has a reduced cross-sectional flow area and the inlet is formed in the reduced cross-sectional flow area. For example, the reduced cross-sectional flow area can have an inwardly tapered surface and the inlet can be formed at least partially on the inwardly tapered surface.

[0017] In one or more embodiments, the inlet is formed in the string of tubing axially closer to the heel portion than the outlet so that when steam is received by the

passageway an axial momentum of the steam is maintained. For example, the passageway can extend less than about fifteen degrees from the inner surface.

[0018] In one or more embodiments, an annulus that is in fluid communication with the outlet is formed in the outer surface of the string of tubing and extends around the circumference thereof. A nozzle can be positioned within the annulus to control the flow of steam received from the outlet.

[0019] Another aspect of the present invention includes a well assembly for injecting steam into a subterranean reservoir. The well assembly includes a string of tubing in fluid communication with a producing zone of a subterranean reservoir. The string of tubing has a substantially vertical section and a substantially horizontal section extending from a lower portion thereof. The substantially horizontal section defines a heel portion at one end and a toe portion at the opposite end. An opening formed on the inner surface of the substantially horizontal section defines an inlet. An opening formed on the outer surface of the substantially horizontal section defines an outlet. A passageway extends between the inlet and the outlet such that steam received by the inlet is delivered to the outlet. A flow conditioning device is positioned in the string of tubing axially closer to the heel portion than the inlet. The flow conditioner has a plurality of vanes extending inwardly from the inner surface of the string of tubing and around the circumference thereof so that when steam is received by the plurality of vanes a more homogenous mixture of vapor and liquid components of the steam is generated.

[0020] In one or more embodiments, the plurality of vanes extending inwardly from the inner surface of the string of tubing are axially spaced to define a conditioning region.

[0021] In one or more embodiments, the plurality of vanes extending inwardly from the inner surface of the string of tubing provide sufficient clearance to allow a logging tool to travel therethrough.

[0022] In one or more embodiments, the flow conditioning device is positioned in the string of tubing a length between about four to six times the diameter of the string of tubing upstream of the inlet.

[0023] In one or more embodiments, the flow conditioning device is carried within the string of tubing. In one or more embodiments, the flow conditioning device is positioned between segments of tubing within the substantially horizontal section of the string of tubing.

[0024] In one or more embodiments, the string of tubing has a reduced cross-sectional flow area and the inlet is formed in the reduced cross-sectional flow area. For example, the reduced cross-sectional flow area can have an inwardly tapered surface and the inlet can be formed at least partially on the inwardly tapered surface.

[0025] In one or more embodiments, the inlet is formed in the string of tubing axially closer to the heel portion than the outlet so that when steam is received by the passageway an axial momentum of the steam is maintained. For example, the passageway can extend less than about fifteen degrees from the inner surface.

[0026] In one or more embodiments, an annulus that is in fluid communication with the outlet is formed in the outer surface of the string of tubing and extends around the circumference thereof. A nozzle can be positioned within the annulus to control the flow of steam received from the outlet.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Figure 1 is a schematic, sectional view of a prior art steam delivery in a horizontal well in the field of hydrocarbon production.

[0028] Figure 2 is a schematic, sectional view of a prior art steam delivery in a horizontal well in the field of hydrocarbon production.

[0029] Figure 3 is a schematic, sectional view of a prior art tubing string distribution assembly for use in a horizontal well in the field of hydrocarbon production.

[0030] Figure 4 is a schematic, sectional view of a tubing string distribution assembly according to an embodiment of the present invention for use in a horizontal well in the field of hydrocarbon production.

[0031] Figure 5 is a schematic, sectional view of a tubing string distribution assembly according to an embodiment of the present invention for use in a horizontal well in the field of hydrocarbon production.

[0032] Figure 6 is a schematic, sectional view of a tubing string distribution assembly according to an embodiment of the present invention for use in a horizontal well in the field of hydrocarbon production.

[0033] Figure 7 is a schematic, sectional view of a tubing string distribution assembly according to an embodiment of the present invention for use in a horizontal well in the field of hydrocarbon production.

[0034] Figure 8 is a schematic, sectional view of a tubing string distribution assembly according to an embodiment of the present invention for use in a horizontal well in the field of hydrocarbon production.

[0035] Figure 9 is a schematic, sectional view of a flow conditioner according to an embodiment of the present invention for use in a horizontal well in the field of hydrocarbon production.

[0036] Figure 10 is a schematic, section view of the flow conditioner of Figure 9 engaging a tubing string steam distribution assembly.

[0037] Figure 11 is a graph of steam phase splitting for a conventional tubing string distribution assembly for use in a horizontal well in the field of hydrocarbon production.

[0038] Figure 12 is a graph of steam phase splitting for a tubing string distribution assembly according to an embodiment of the present invention for use in a horizontal well in the field of hydrocarbon production.

DETAILED DESCRIPTION

[0039] Referring initially to prior art Figure 1, a cross sectional view shows a wellbore 11 having vertical section 11A and horizontal section 11B. Wellbore 11 provides a flow path between the well surface and producing sand or reservoir 31.

Tubing string 13 and slotted liner 15 are also shown in Figure 1. The horizontal section 11B of tubing string 13 includes a heel portion 13A and an opposite toe portion 13B. Slotted liner 15 is a completion device lining horizontal section 11B of wellbore 11 and is typically isolated by a lead seal 17 from vertical section 11A of wellbore 11. Live steam is supplied via tubing string 13 and exits from toe portion 13B at end 19. The steam flow is as indicated by arrows 21. Direct impingement of live steam onto slotted liner 15 at the area numbered 23 can potentially cause erosion and collapse of the liner 15, which is an undesirable condition. Also, using this technique the steams' heat is concentrated near toe portion 13B in areas 25 and 27 of reservoir 31 rather than along the length of slotted liner 15.

[0040] Referring now to prior art Figure 2, wellbore 29 has vertical section 29A, which goes to the surface, and horizontal section 29B that penetrates a long horizontal section of producing sand or reservoir 31. Slotted liner 37 lines horizontal section 29B of wellbore 29. Tubing string 33 is run in from the surface and, on the lower end thereof is plugged off by plug 35. The horizontal section 29B of tubing string 33 includes a heel portion 33A and an opposite toe portion 33B. The length of tubing string 33, prior to the plug 35, is provided with spaced apart drilled holes 39 along its entire horizontal section between heel portion 33A and toe portion 33B. Each drilled hole 39 is covered with a sacrificial impingement strap 41. Sacrificial impingement straps 41 are constructed of a carbon steel material and may be ceramic coated if desired. Sacrificial impingement straps 41 are welded to tubing string 33 with an offset above each drilled hole 39.

[0041] A steam generator source (not shown) is located at the surface and provides an input of steam into tubing string 33. The steam travels down tubing string 33 to its lower horizontal section 29B where it exits via drilled holes 39. As will be described, while steam can exit tubing string 33 between heel portion 33A and toe portion 33B, uniform mass distribution and latent heat is not achieved along horizontal section 29B.

[0042] Referring to Figure 3, a cross-section of a portion of tubing string 33 that is located within slotted liner 37 of Figure 2 is shown. Sacrificial impingement straps 41 are not shown in Figure 3. Tubing string 33 includes inner surface 43 and outer surface 45. A plurality of drilled holes 39 extend from inner surface 43 to outer surface 45. Each drilled hole 39 extends radially outward, substantially perpendicular to inner surface 43. Typically, drilled holes 39 are intermittently spaced between heel portion 33A and toe portion 33B of tubing string 33 for delivering steam to reservoir 31. A two-phase fluid F, typically steam having vaporous water and liquid water droplets D, travel through tubing string 33 for delivery into oil sands or reservoir 31.

[0043] When two-phase fluid F is under low velocity conditions, such as less than 40 feet per second, the flow is stratified. In particular, gravity causes the liquid phase to travel along the bottom portion of the pipe. When superficial vapor and liquid velocities are both low, the interface between the liquid and vapor phases is smooth. As vapor velocities begin to increase, the interface becomes wavy. As the superficial liquid velocities increase, the flow tends to form in slugs or large waves of liquid (short in duration) separated by stratified wavy flow. At very high superficial

flow velocities, the liquid forms a ring on the inner surface of the pipe wall and the vapor travels in the center of the pipe. At high superficial vapor velocities and steam qualities, the liquid becomes entrained in the vapor core such that the pipe is filled with vapor except for small droplets of liquid mist.

[0044] Liquid droplets D have higher densities and thus higher momentum than the vaporous water, which restricts the ability of liquid droplets D to change direction. When liquid droplets D traveling in the main flow of fluid F encounter a smaller vapor flow, or velocity profile, toward drilled holes 39, liquid droplets D experience a drag force to change direction. However, the momentum of liquid droplets D opposes this change of direction, thereby resulting in less movement toward drilled holes 39. In the embodiment shown in Figure 3, the liquid droplets entrained in the vapor core must make sharp, radially outward turns with respect to the flow of fluid F for liquid droplets to enter drilled holes 39 for delivery into reservoir 31. This results in the extracted steam having less liquid droplets D such that the quality of the steam delivered at the upstream portion of tubing string 33 is different from the steam delivered to the downstream portion of tubing string 33. In particular, more liquid droplets will be delivered toward the downstream toe portion 33A of tubing string 33 than to heel portion 33B. Such a phenomenon is known as “phase splitting.”

[0045] In Figures 4-8, alternative tubing configurations are provided to counteract the phase splitting described above so that more uniform quality steam is delivered to reservoir 31 from both the upstream and downstream portions of the respective tubing strings. More particularly, Figures 4-8 each show a portion of

tubing sub or string of tubing 111 disposed between the heel portion and the toe portion of the horizontal section of a wellbore. As will be described, steam generated at the surface is delivered to tubing 111 for a more uniform steam quality distribution along the horizontal section of a wellbore into reservoir 31.

[0046] Referring to Figure 4, tubing 111 includes a plurality of openings 117 extending from inner surface 113 to outer surface 115. Openings 117 include an opening formed on inner surface 113 that defines inlet 117A, an opening formed on outer surface 115 that defines outlet 117B, and passageway 117C extending between inlet 117A and outlet 117B such that steam received by inlet 117A is delivered to outlet 117B. Inlet 117A is formed in the string of tubing axially closer to the heel portion than outlet 117B. While openings 117 are illustrated as having about fifteen degree outward angles to the flow of fluid F, it should be understood that the optimum angle for openings 117 is the smallest angle allowed by machining tools.

[0047] A plurality of openings 117 are preferably intermittently spaced along the length of tubing 111. For example, openings 117 can be positioned every 100 to 500 feet along tubing 111. In general, spacing of openings 117 will be dependent upon the particular reservoir characteristics. One skilled in the art will appreciate that isolation between a first group of openings 117 and a second group of openings 117 can be utilized. Furthermore, conventional sand control mechanisms, such as a sand screen, can be placed adjacent to openings 117. In one embodiment, tubing 111 ends near the heel portion and openings 117 are configured in the liner.

[0048] Openings 117 reduce the directional change necessary for liquid droplets to enter openings 117, thereby making it easier for liquid droplets to exit

tubing 111. In particular, when steam is received by passageway 117C an axial momentum of the steam is maintained. Accordingly, the difference in steam quality delivered from the upstream portion of tubing 111 compared with the downstream portion of tubing 111 is reduced as more liquid droplets entrained in the vapor core are able to exit openings 117.

[0049] Referring to Figure 5, an alternative tubing configuration is provided to counteract the segregation of vapor and liquid in Fluid F so that more uniform quality steam is delivered to reservoir 31 from both the upstream and downstream portions of the respective tubing strings. As shown in Figure 5, tubing 111 includes mandrel portion or tubing sub 120 with a reduced cross-sectional flow area and a plurality of openings 117 extending from inner surface 113 to outer surface 115. Openings 117 include an opening formed on inner surface 113 that defines inlet 117A, an opening formed on outer surface 115 that defines outlet 117B, and passageway 117C extending between inlet 117A and outlet 117B such that steam received by inlet 117A is delivered to outlet 117B. Inlet 117A and outlet 117B are formed at substantially the same axial locations between the heel and the toe of the string of tubing. As with the embodiment in Figure 4, a plurality of openings 117 are preferably intermittently spaced along the length of tubing 111, with each opening 117 being associated with a tubing sub 120.

[0050] Tubing sub 120 includes inwardly tapered surface 121 that extends between the portion of inner surface 113 having the normal diameter of tubing 111 and reduced diameter surface 123, which is where openings 117 are located. Inwardly tapered surface 121 is located upstream of openings 117 to condition the

flow of fluid F. Tubing sub 120 can also include outwardly tapered surface 125 that is positioned downstream of openings 117, and that extends from reduced diameter surface 123 to the portion of inner surface 113 having the normal diameter of tubing 111.

[0051] The reduction in the diameter of tubing 111 at inwardly tapered surface 121 increases the velocity of fluid F, while the increase in diameter from outwardly tapered surface 125 reduces the velocity of fluid F. The continued variation of the velocity of fluid F along the length of tubing 111 induces mixing of liquid droplets D with the vaporous water prior to flowing toward openings 117. Mixing fluid F can help provide a more uniform steam quality being delivered along the length of tubing 111. By way of example, if tubing 111 were a conventional string of 4.5 inch tubing, inner diameter 113 would be about 3.96 inches. The desired velocity change could be achieved when reduced diameter surface 123 is equivalent to the inner diameter of standard 2 3/8 inch tubing, which is about 2.44 inches. Preferably inwardly and outwardly tapered surfaces 121, 125 are at about fifteen degree respective inclines or declines.

[0052] Referring to Figure 6, an alternative tubing configuration is shown where tubing 111 includes openings 117 extending at an angle from inner surface 113 to outer surface 115. Openings 117 include an opening formed on inner surface 113 that defines inlet 117A, an opening formed on outer surface 115 that defines outlet 117B, and passageway 117C extending between inlet 117A and outlet 117B such that steam received by inlet 117A is delivered to outlet 117B. Inlet 117A is formed in the string of tubing axially closer to the heel portion than outlet 117B.

[0053] In the embodiment, the diameter of inner surface 113 adjacent openings 117 is reduced, thereby making the thickness of tubing 111 immediately upstream and downstream of openings 117 thicker than in the embodiment shown in Figure 4. Similar to Figure 5, tubing sub 120 includes inwardly extending tapered surface 121 that extends between the portion of inner surface 113 having the normal diameter of tubing 111 and reduced diameter surface 123, which is where openings 117 are located. Inwardly tapered surface 121 is located upstream of openings 117 to condition the flow of fluid F. Outwardly tapered surface 125 is positioned downstream of openings 117 and extends from reduced diameter surface 123 to the portion of inner surface 113 having the normal diameter of tubing 111.

[0054] Tubing sub 120 in Figure 7 is substantially the same as in Figures 5 and 6 except that openings 117 extend axially through tubing 111 from inwardly tapered surface 121. Openings 117 include an opening formed on inner surface 113 that defines inlet 117A, an opening formed on outer surface 115 that defines outlet 117B, and passageway 117C extending between inlet 117A and outlet 117B such that steam received by inlet 117A is delivered to outlet 117B. Inlet 117A is formed in the string of tubing axially closer to the heel portion than outlet 117B. Preferably, openings 117 are as close to parallel with the axial flow of fluid F as possible with machining capabilities. Locating openings 117 on inwardly tapered surface 121 allows liquid droplets to enter outlets 117 with minimal deviation from the path of liquid droplets D prior to encountering reduced diameter surface 123. For example,

the inwardly tapered surface 121 can be tapered about fifteen degrees from an axis of the tubing 111 and the inlet can be about parallel to the axis of the tubing 111.

[0055] As shown in Figure 7, openings 117 extend axially to an annulus 129 formed radially outward of reduced diameter surface 123. In particular, annulus 129 is formed in the outer surface 115 of the string of tubing and extends around the circumference thereof. However, in some embodiments annulus 129 is not present and openings 117 axially extend between inwardly tapered surface 121 and outer surface 115.

[0056] The embodiment shown in Figure 8 is substantially the same as Figure 7 except that nozzles 131 are positioned in annulus 129 to receive fluid from openings 117. Nozzles 131 can be sized to more precisely control the rate of steam delivery into reservoir 31 from each opening 117 along tubing 111. Examples of nozzles 131 include an orifice with a reduced cross-section or a venturi. Additionally, because nozzles 131 are controlling the rate of steam delivery in this embodiment, openings 117 can be enlarged to enhance liquid droplet D capture to a predetermined amount.

[0057] As will be readily understood by those skilled in the art, tubing 111 for each of the embodiments shown in Figures 4-8 can be a tubing sub that is positioned between pairs of tubing rather than being integrated in the string of tubing itself. This type of delivery can prevent steam migration into the underlying water zone or into the upper desaturated portion of the reservoir. Also by delivering the steam uniformly along the entire horizontal portion of the producing zone penetrated by the horizontal portion of the well, any potential damage to a production liner in this horizontal bore

is reduced. Furthermore, the above embodiments reduce phase splitting along the horizontal portion of the wellbore, thus delivering a uniform steam quality and ensuring uniform latent heat to the reservoir.

[0058] Referring to Figure 9, a flow conditioner or conditioning sub 133 includes a conditioner housing 135 that is substantially tubular. Frusto-conical end pieces 137,139 are positioned at each end of housing 135 with an opening 141 being formed at upstream end piece 137 and an opening 143 being formed at downstream end piece 139. End pieces 137,139 are tapered such that openings 141, 143 have a smaller diameter than housing 135.

[0059] Carried within housing 135 is a conditioning mechanism 145 extending coaxially with housing 135. Conditioning mechanism 145 includes a plurality of inwardly extending vanes or stators 147 that are intermittently spaced around the inner circumference of conditioning mechanism 145. Stators 147 typically extend axially downstream, and provide enough clearance between their respective radially inward tips so as to define a clearance 148 through which conventional logging tools can be deployed and retrieved.

[0060] Each set of circumferentially spaced stators define a conditioning stage 149. Preferably, conditioning mechanism 145 includes a plurality of spaced-apart conditioning stages 149 along the length of conditioning mechanism 145 to create a conditioning region 151. Typically a conditioning region of about ten (10) to thirty (30) inches is sufficient to obtain homogeneous mixture of the two-phase fluid F. For example, inwardly extending vanes 147 can be made longer to achieve a greater amount of mixing over a shorter length. Furthermore, the flow of two-phase

fluid F can be increased to obtain a greater amount of mixing. Components of conditioning mechanism 145 are preferably hardened metals for the severe environmental operating conditions associated with steam distribution for hydrocarbon production.

[0061] Referring to Figure 10, conditioning sub 133 is positioned upstream of steam distribution assembly 153. For example, flow conditioning device can be positioned in the string of tubing a length of approximately four to six times the diameter of tubing 111 upstream of opening 117. Accordingly, for 4.5 inch tubing the conditioning sub 133 is positioned approximately between 18 and 27 inches upstream of opening 117. The positioning of conditioning sub 133 can however be positioned closer to or farther from steam distribution assembly 153 if desired such as two to ten times the diameter of tubing 111. Openings 141, 143 of conditioning sub 133 engage segments of tubing 111, such as tubing 111 of upstream steam distribution assembly 153. Distribution assembly 153 can be, for example, those discussed in Figures 4-8 or another steam distribution assembly such as the Equalizer Steam Distribution Sub commercially available from Baker Hughes.

[0062] Conditioning the flow of fluid F, or generating a more homogenous mixture, immediately upstream of distribution assembly 153 will result in a more representative sample or extraction of the two-phase fluid F. In annular flow regimes, conditioning sub 133, through the plurality of conditioning stages 149, helps to remove water film or collected condensation from the inner surface of tubing 111 and to homogenize it with the vapor in fluid F. The inner diameter of housing 135 and

conditioning mechanism 145 can be increased in order to increase the size and number of stators 147 for more conditioning as desired.

EXAMPLE I

[0063] As will be described below, the performance of an alternative tubing configuration using flow conditioner or conditioning sub 133 was compared to a conventional tubing string distribution assembly using a surface horizontal steam injection facility. The horizontal steam injection facility is capable of testing a wide range of full-sized downhole completion equipment, such as tubing and liner flow control devices, at the surface at controlled conditions. Additional details of the surface horizontal steam injection facility can be found in S.P.E. paper #132410, titled, “Addressing Horizontal Steam Injection Completions Challenges with Chevron’s Horizontal Steam Injection Test Facility.”

[0064] The steam quality extracted from each tubing configuration was measured for all possible combinations of three inlet pressures, two inlet steam qualities, six inlet rates and two pressure extraction ratios. The figures below show the difference between the steam quality extracted through the device’s exit and the steam quality flowing in the tubing as a function of the tubing superficial vapor velocity.

[0065] Figure 11 shows steam quality results obtained using 4.5 inch tubing with four one-quarter inch holes drilled perpendicular from horizontal and phased 90 degrees around the circumference. This tubing device is similar to that shown in Figure 3, where liquid droplets must make a sharp 90 degree turn with respect to the

flow of fluid for the liquid droplets to enter the holes for delivery into the reservoir. The range of steam quality differences between the entrance and extraction of the device has a large variation of -15 to +15 steam quality units.

[0066] Figure 12 shows steam quality results conducted using the flow conditioning device positioned upstream of the device that produced the results shown in Figure 11. Improvement is seen over the entire velocity range with significant improvement above 40 ft/sec which roughly corresponds to the transitional velocity from stratified to annular flow. In this annular flow regime the steam quality differences are centered around a value greater than zero but show a significantly smaller variation and thus are more predictable. The steam quality over the entire velocity range yields a tighter steam quality difference band compared to the steam quality obtained using the four 1/4" holes drilled perpendicular from horizontal shown in Figure 11. As previously discussed, flow conditioning device induces mixing of liquid droplets with the vaporous water prior to the steam exiting via the drilled holes.

[0067] While the invention has been shown in only some of its forms, it should be apparent to those skilled in the art that it is not so limited, but susceptible to various changes without departing from the scope of the invention. For example, tubing 111 could end near the heel portion such that conditioning sub 133 and steam distribution assembly 153 are configured and intermittently spaced within the liner.

WHAT IS CLAIMED IS:

1. A well assembly for injecting steam into a subterranean reservoir, the well assembly comprising:

a string of tubing in fluid communication with a producing zone of a subterranean reservoir, the string of tubing comprising a substantially vertical section and a substantially horizontal section extending from a lower portion of the substantially vertical section, the substantially horizontal section defining at one end a heel portion and at an opposite end a toe portion;

an opening formed on the inner surface of the substantially horizontal section that defines an inlet;

an opening formed on the outer surface of the substantially horizontal section that defines an outlet;

a passageway extending between the inlet and the outlet such that steam received by the inlet is delivered to the outlet; and

a flow conditioning device being positioned in the string of tubing axially closer to the heel portion than the inlet to generate a more homogenous mixture of the vapor and liquid components of the two-phase steam.

2. The well assembly of claim 1, wherein the flow conditioning device comprises a stator.

3. The well assembly of claim 1, wherein the flow conditioning device comprises a plurality of axially spaced stators thereby defining a conditioning region.

4. The well assembly of claim 1, wherein the flow conditioning device comprises a plurality of vanes extending inwardly from the inner surface of the string of tubing and around the circumference thereof.
5. The well assembly of claim 1, wherein the flow conditioning device is adapted to allow a logging tool to travel therethrough.
6. The well assembly of claim 1, wherein the flow conditioning device is positioned in the string of tubing a predetermined length upstream of the inlet, the predetermined length being between about four to six times the diameter of the string of tubing..
7. The well assembly of claim 1, wherein the flow conditioning device is carried within the string of tubing.
8. The well assembly of claim 1, wherein the flow conditioning device is positioned between segments of tubing within the substantially horizontal section of the string of tubing.
9. The well assembly of claim 1, wherein:
the string of tubing further comprises a reduced cross-sectional flow area; and
the inlet is formed in the reduced cross-sectional flow area.

10. The well assembly of claim 1, wherein the inlet is axially closer to the heel portion than the outlet so that when steam is received by the passageway an axial momentum of the steam is maintained.

11. The well assembly of claim 1, further comprising:

an annulus formed in the outer surface of the string of tubing that extends around the circumference thereof, the annulus being in fluid communication with the outlet; and

a nozzle positioned within the annulus to control the flow of steam received from the outlet.

12. A well assembly for injecting steam into a subterranean reservoir, the well assembly comprising:

a string of tubing in fluid communication with a producing zone of a subterranean reservoir, the string of tubing comprising a substantially vertical section and a substantially horizontal section extending from a lower portion of the substantially vertical section, the substantially horizontal section defining at one end a heel portion and at an opposite end a toe portion;

an opening formed on the inner surface of the substantially horizontal section that defines an inlet;

an opening formed on the outer surface of the substantially horizontal section that defines an outlet;

a passageway extending between the inlet and the outlet such that steam received by the inlet is delivered to the outlet; and

a flow conditioning device being positioned in the string of tubing axially closer to the heel portion than the inlet, the flow conditioner comprising a plurality of vanes extending inwardly from the inner surface of the string of tubing and around the circumference thereof so that when steam is received by the plurality of vanes a more homogenous mixture of vapor and liquid components of the steam is generated.

13. The well assembly of claim 12, wherein the plurality of vanes extending inwardly from the inner surface of the string of tubing and around the circumference thereof are axially spaced in the string of tubing, thereby defining a conditioning region.

14. The well assembly of claim 12, wherein the flow conditioning device is positioned in the string of tubing a predetermined length upstream of the inlet, the predetermined length being between about four to six times the diameter of the string of tubing.

15. The well assembly of claim 12, wherein the flow conditioning device is carried within the string of tubing.

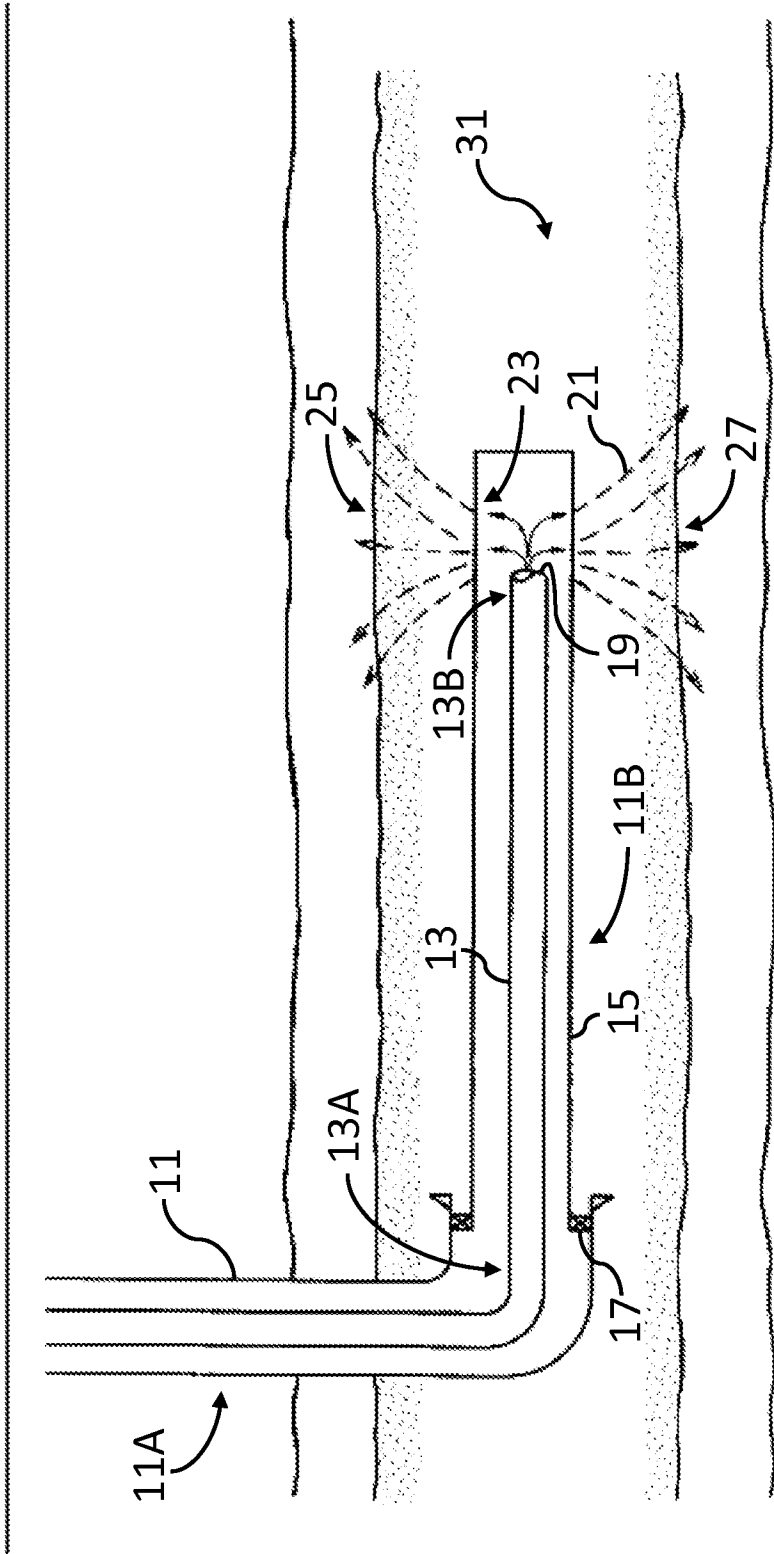
16. The well assembly of claim 12, wherein the flow conditioning device is positioned between segments of tubing within the substantially horizontal section of the string of tubing.

17. The well assembly of claim 12, wherein:
the string of tubing further comprises a reduced cross-sectional flow area; and

the inlet is formed in the reduced cross-sectional flow area.

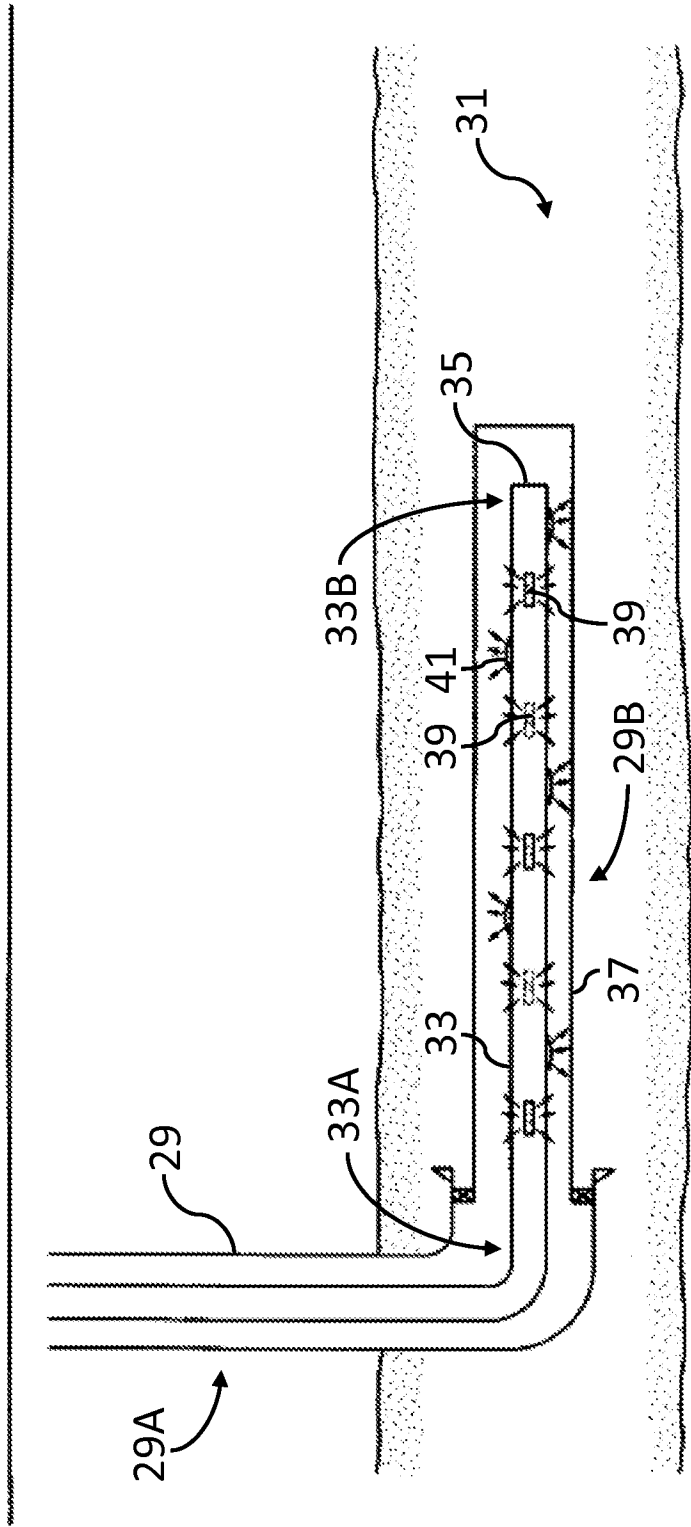
18. The well assembly of claim 12, wherein the inlet is axially closer to the heel portion than the outlet so that when steam is received by the passageway an axial momentum of the steam is maintained.

19. The well assembly of claim 12, wherein the plurality of vanes extending inwardly from the inner surface of the string of tubing provide sufficient clearance to allow a logging tool to travel therethrough.



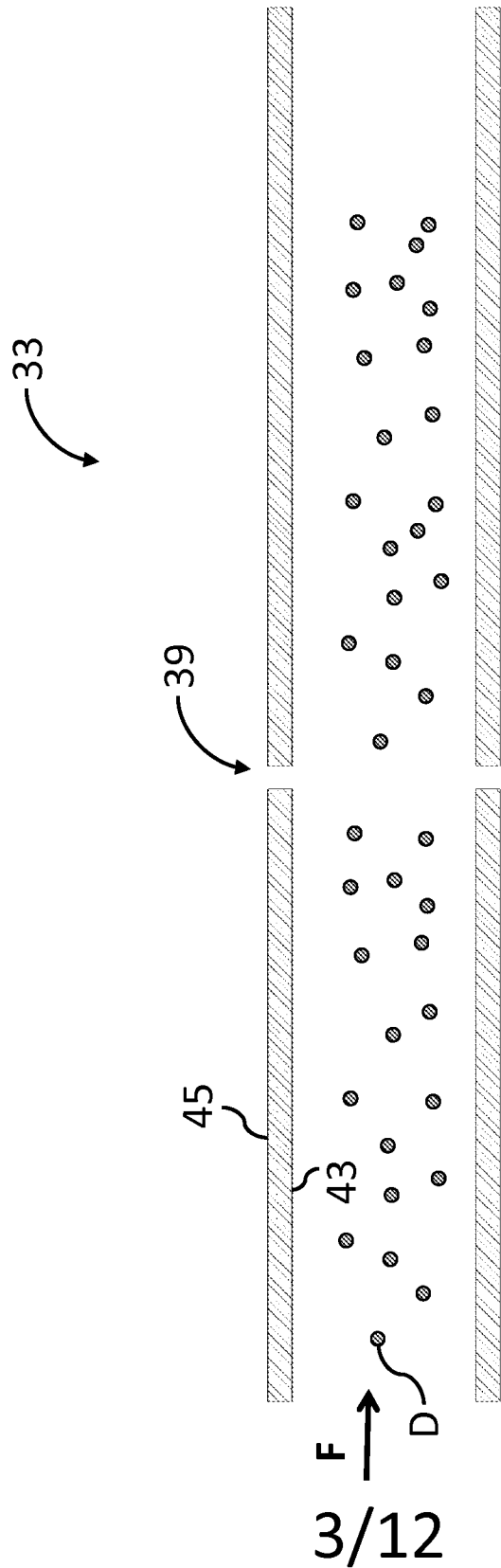
(PRIOR ART)

FIG. 1



(PRIOR ART)

FIG. 2



(PRIOR ART)

FIG. 3

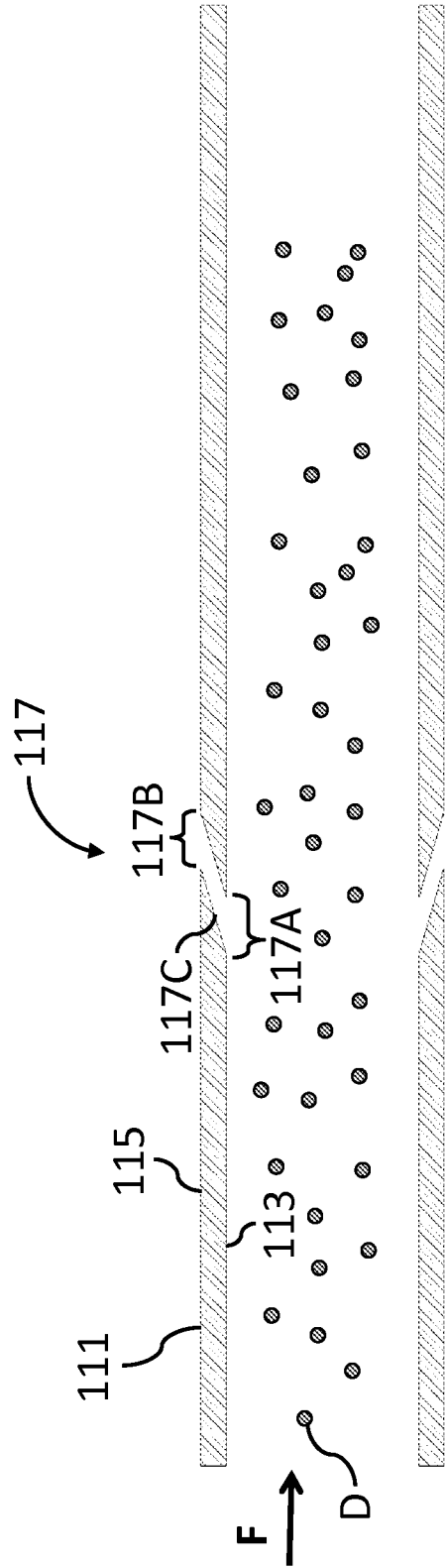


FIG. 4

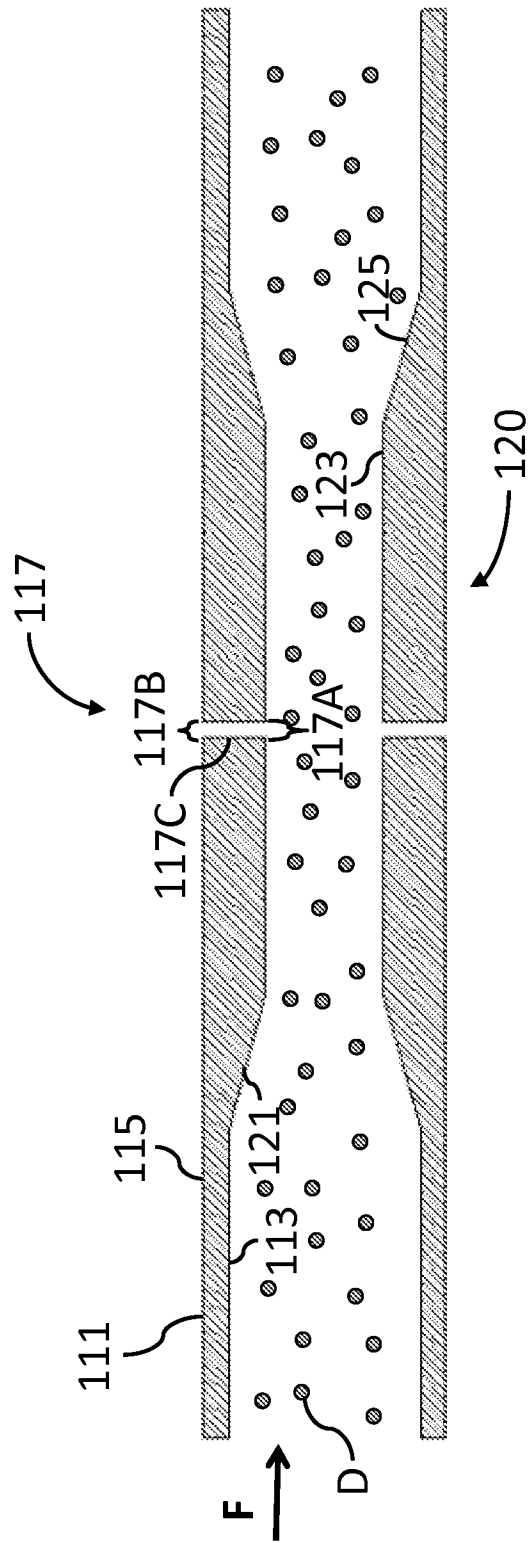


FIG. 5

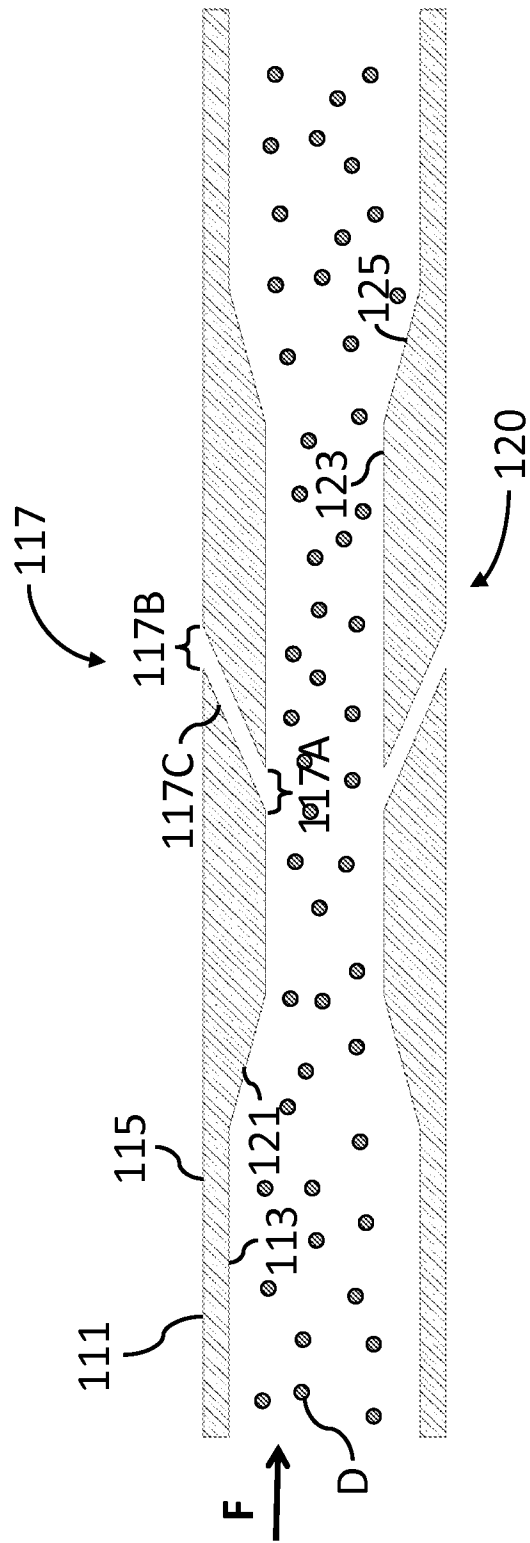


FIG. 6

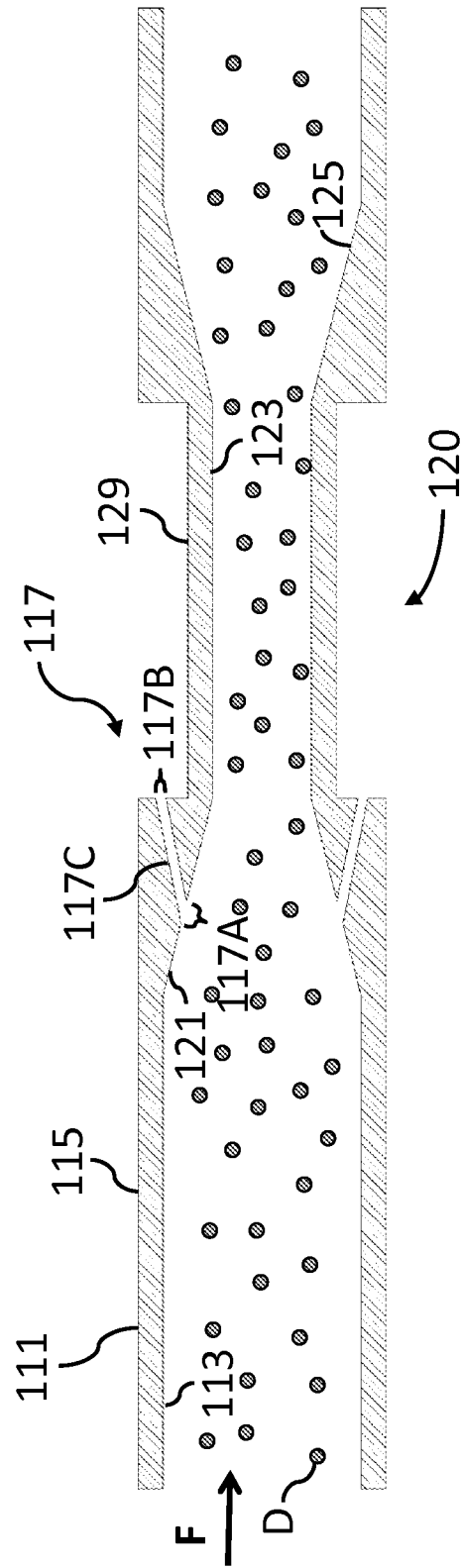


FIG. 7

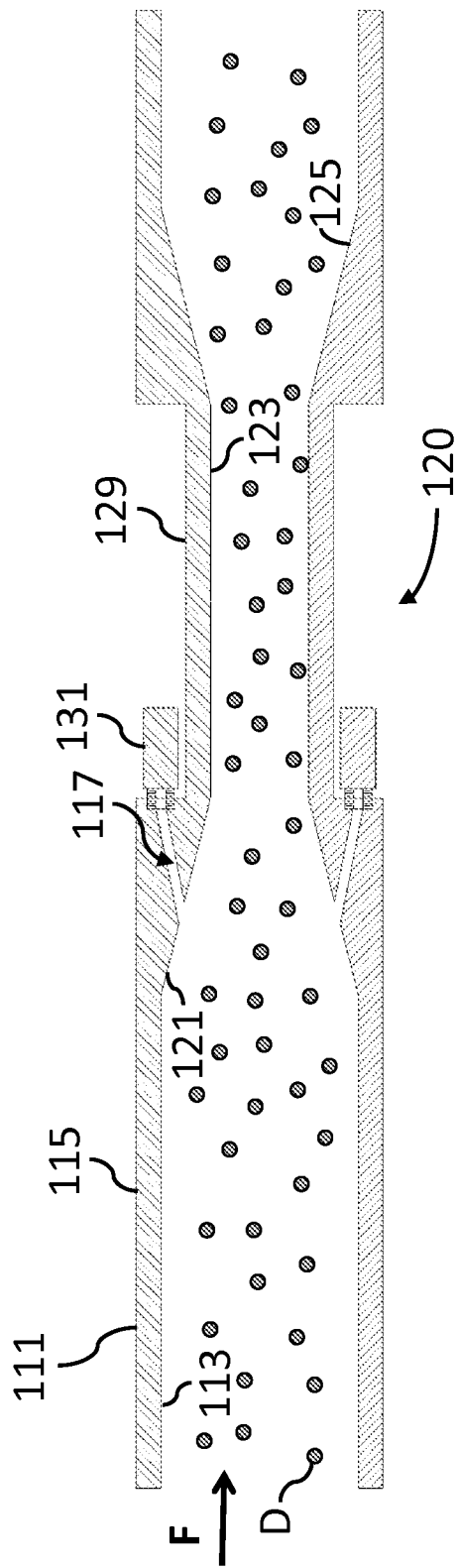


FIG. 8

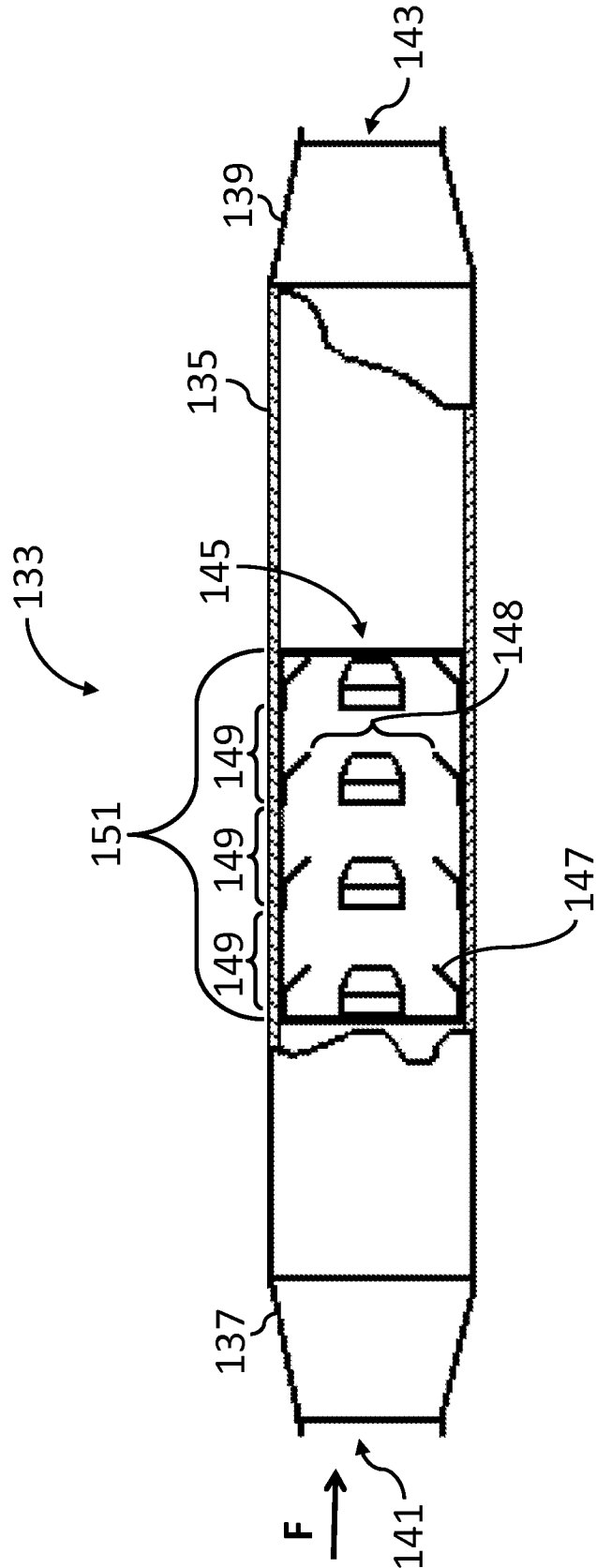


FIG. 9

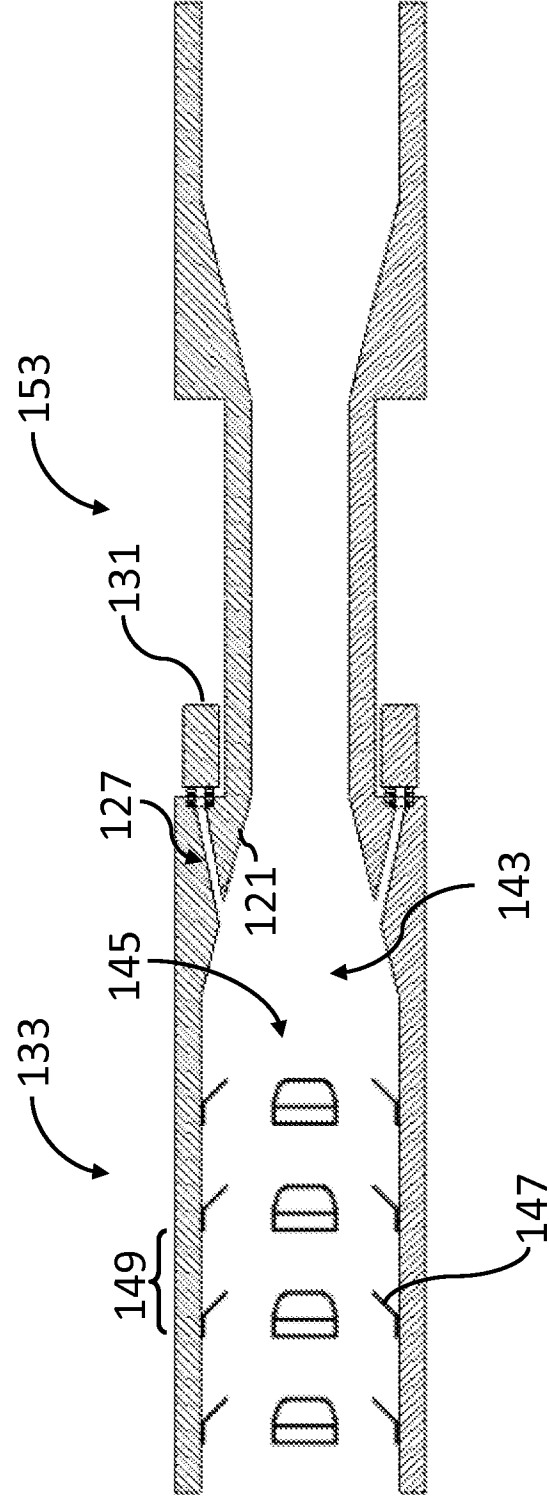


FIG. 10

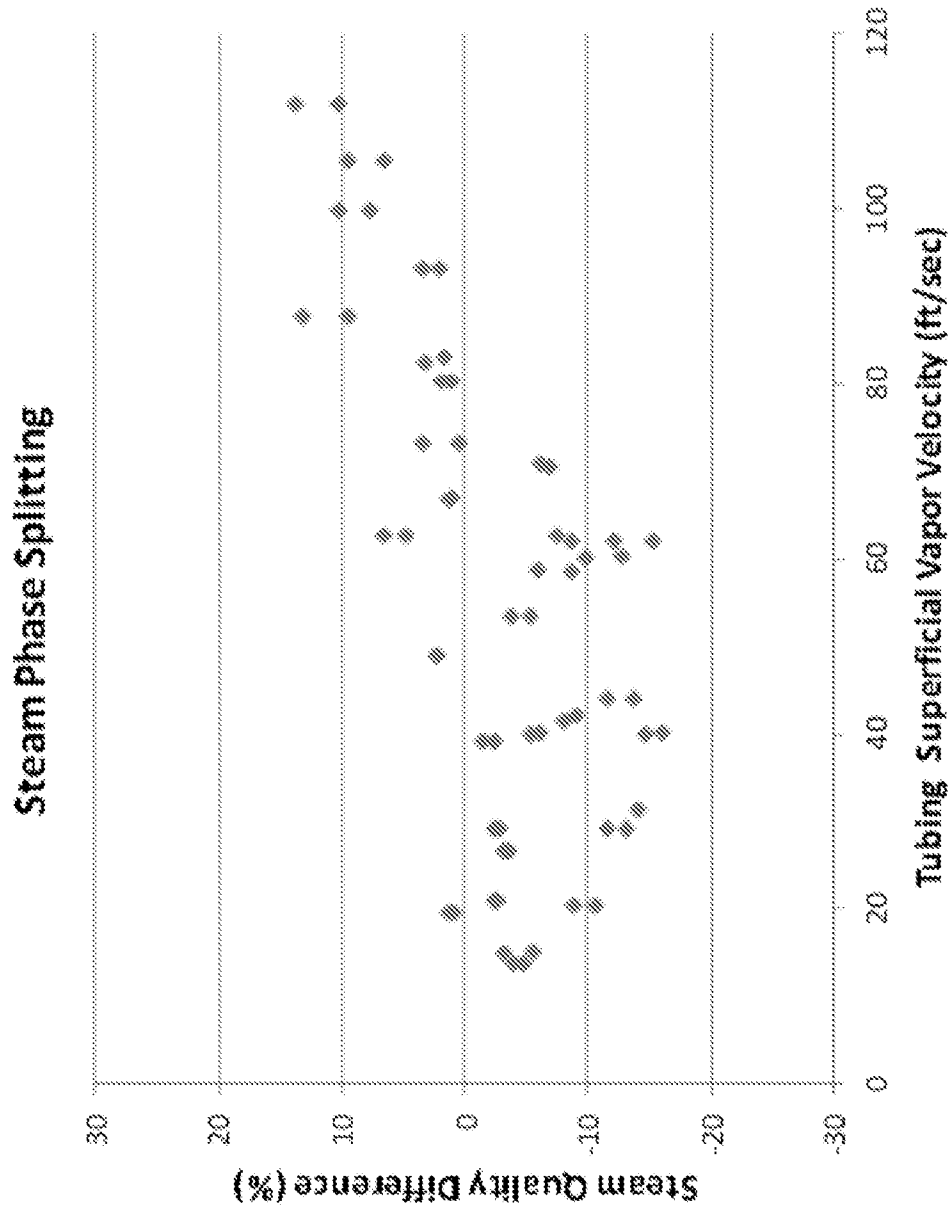


FIG. 11

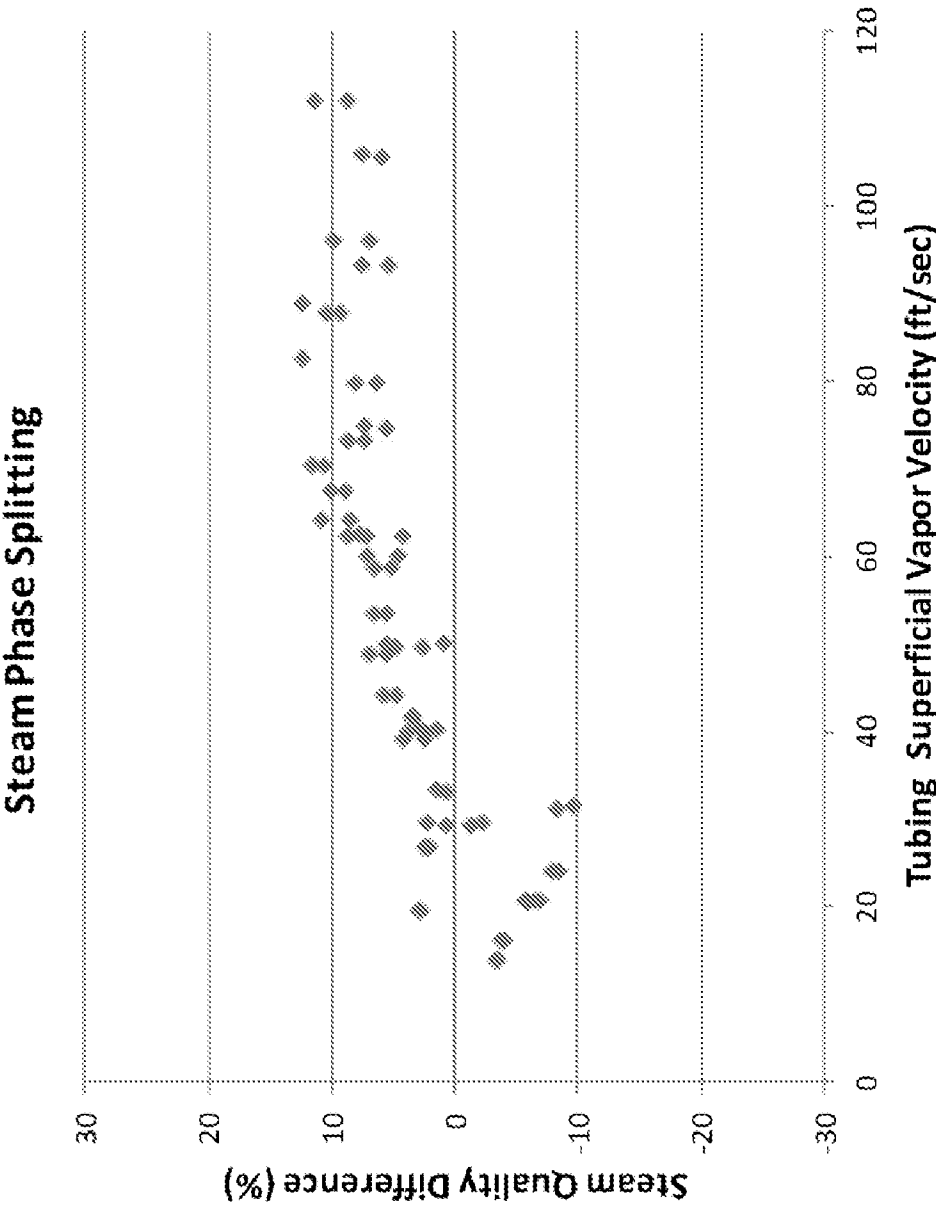


FIG. 12