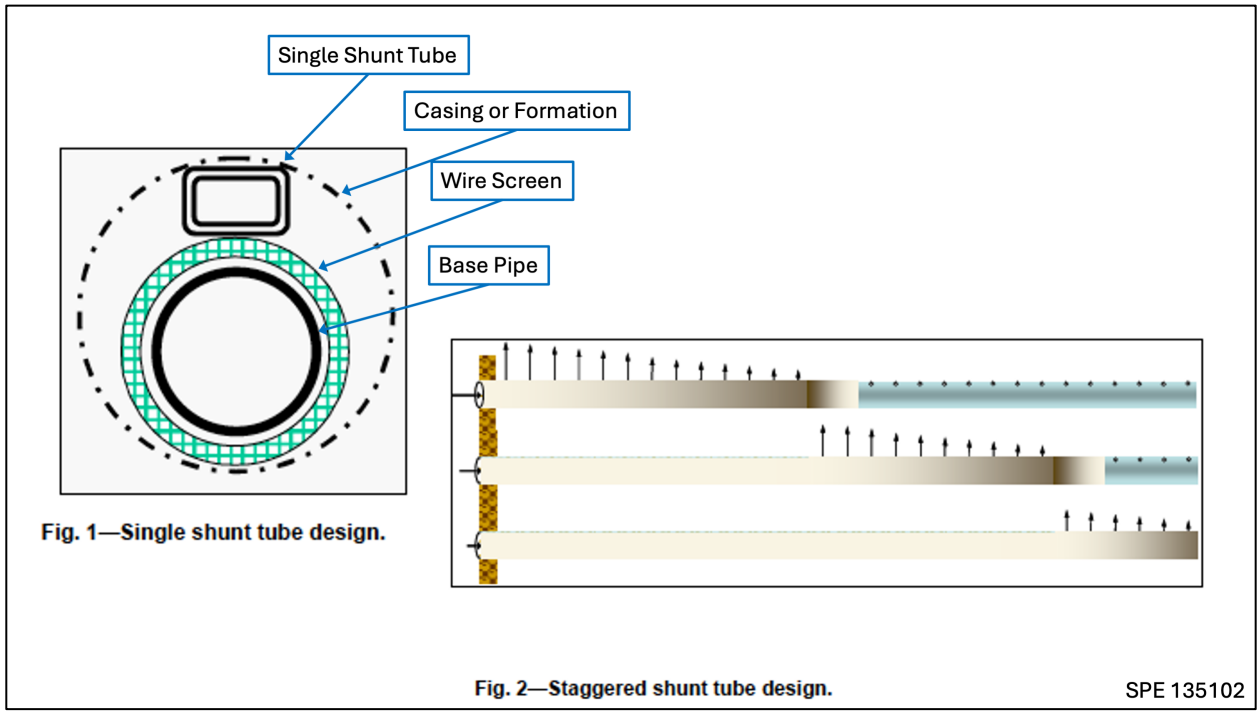


Id. at Fig. 1 (annotated), Fig. 2.

120. Hecker's Figure 1 illustrated the original shunt design, which included one continuous ported shunt tube installed externally of the screen. *Id.* at 2, Fig. 1. This design was limited to gravel packing short intervals of about 100 feet. *Id.* at 2. The design was then modified to a staggered shunt tube design, as shown in Figure 2, in an attempt to gravel pack longer intervals. *Id.* at 2, Fig. 2. This staggered design included multiple shunt tubes wherein the port or orifice locations on each shunt tube were staggered as shown in Figure 2. *Id.*

121. However, this design also had limitations. Due to the leak-off at the orifice interface, ultimately there is a limit to what effective length single shunt tubes could pack. This is shown in Figure 2 above. Also, as fluid leak-off continues, the

sand slurry concentration increases and could plug the shunt if too much leak-off occurs and too little carrier fluid remains to carry the gravel.

122. Also, as fluid leaks off the concentration of gravel in the remaining slurry increases. This is shown in the excerpt from Figure 15 below and reported by many in the industry, including Yeh2.

123. One topic Yeh2 covered was gravel slurry leak-off. *See supra* §VIII.E. Gravel slurry is a combination of sand or gravel and carrier fluid formulated at a starting concentration. *See supra* §VIII.B. However, as the gravel slurry is pumped down the horizontal, some of the carrier fluid will "leak-off" from the slurry thereby dehydrating it. The result is that the gravel slurry becomes more concentrated, or viscous, as it travels down toward the toe. Leak-off could cause gravel accumulation in the manifold in extreme length intervals. EX1006 at 5. Yeh2's Figure 14 shown below illustrated how distance between the manifold and the first nozzle was inversely proportional to the leak-off rate, with a six-foot distance (**solid purple line**) having a lower rate compared to a one-foot distance (**dashed blue line**):

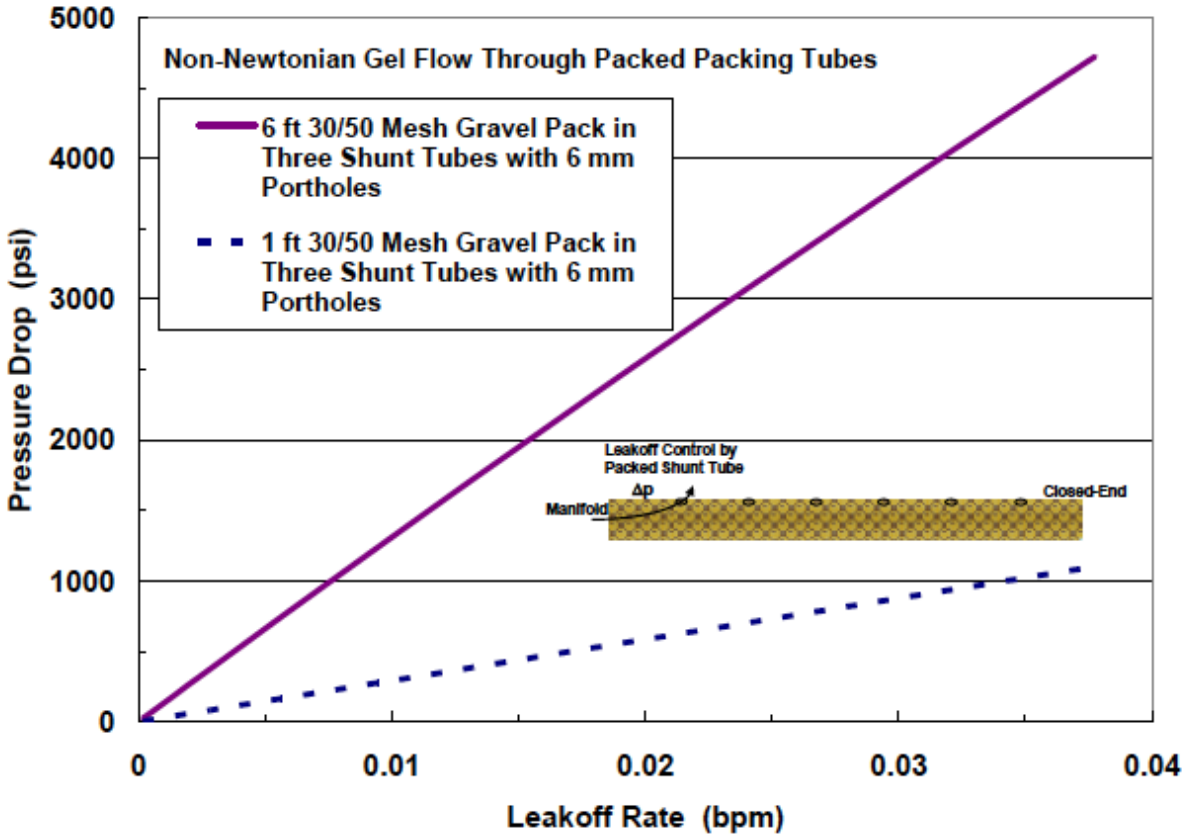
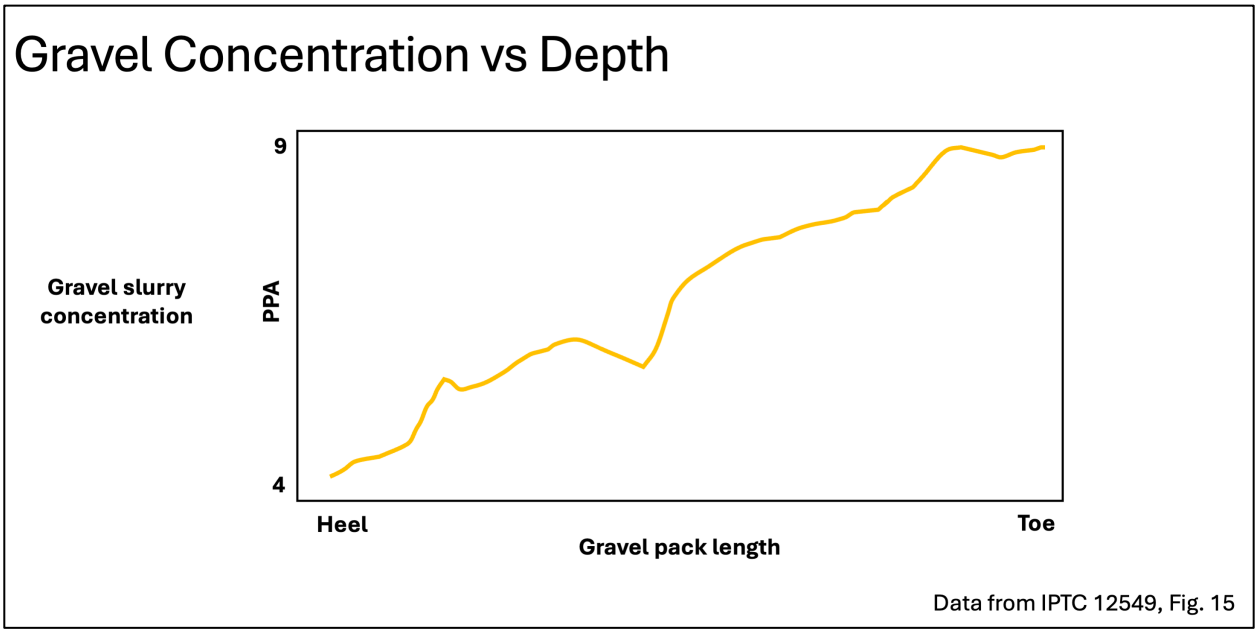


Figure 14 Leakoff through packed shunt tube

Id. at Fig. 14.

124. Yeh2's Figure 15 illustrated how the gravel slurry dehydrated as it was pumped down the horizontal. Specifically, in a 5,000-feet horizontal gravel pack, a slurry starting at 4 PPA (pound per added gallon of carrier fluid) could—through dehydration at the orifices—result in a 9 PPA concentration at the end of the wellbore. I provide a simplified rendering of these data in Figure 15 below:



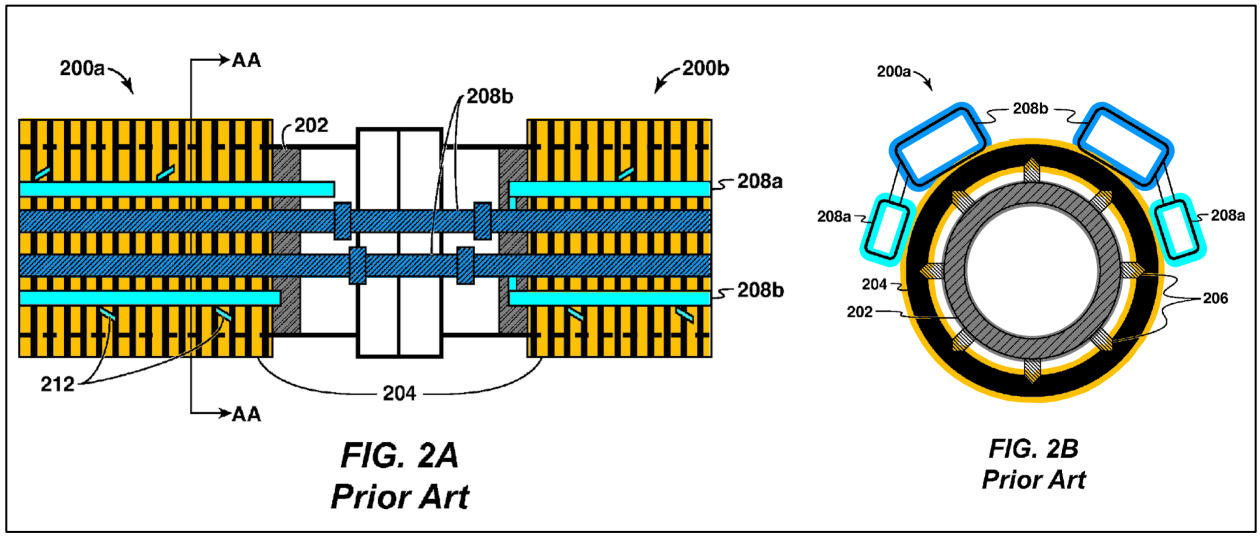
See id. at Fig. 15.

4. Separate Transport & Packing Tubes

125. To extend the length and improve the gravel packing process, dedicated tubes for transporting fluid, and packing intervals were introduced in the early 2000s. An example of this design was shown in the '476 Patent. The '476 Patent improved on APT previously disclosed by Jones' group (illustrated in Figure 2 (below)). EX1010 at 7:44-48 (referencing U.S. Patent Nos. 4,945,991; 5,113,935; 5,515,915; and 6,227,303).

126. In Figure 2, which I provide annotated below, the '476 Patent provided illustrations of "embodiments of conventional sand control devices jointed together within a wellbore." EX1010 at 7:23-24. Figure 2A depicted a sand control device 200a joined to a sand control device 200b via a base pipe 202 (**dark gray**) with each

sand control device 200 surrounded by a sand screen 204 (orange). *Id.* at 7:23-27. Figure 2B provided a cross-sectional view of Figure 2A at line AA–AA. *Id.* at 7:43-44. Disposed about each sand screen 204 were shunt tubes 208. *Id.* at 7:31-33. The shunt tubes included packing tubes 208a (light blue) and transport tubes 208b (blue). *Id.* at 7:33-35. The packing tubes 208a could have at least one nozzle 212 wherein the gravel slurry flowed from the packing tubes 208a and into the annulus between the sand screen 204 and wall of the wellbore. *Id.* at 7:35-38.



Id. at Figs. 2A-2B (annotated).

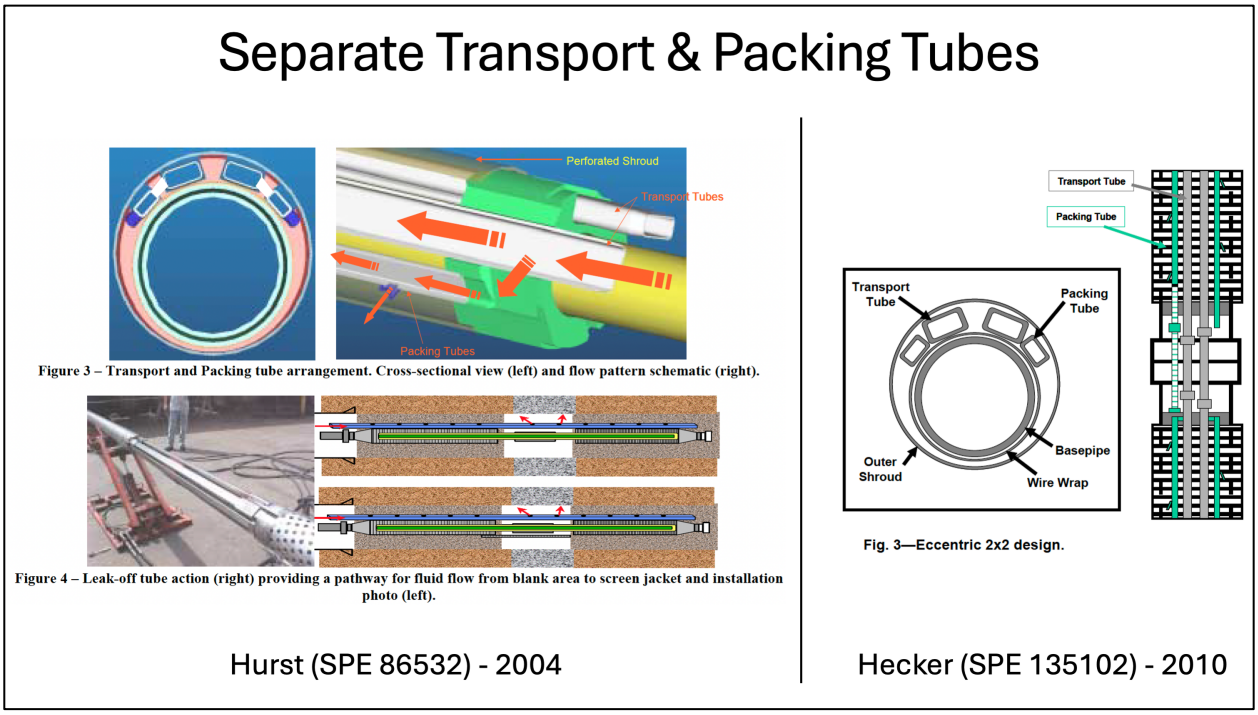
127. In this design, packing tubes were dedicated to a single screen and transport tubes ran the entire length of the completion. This allowed the orifice sizing and placement to be limited to a 20' to 40' length of the screen versus the much longer lengths in conventional designs. Due to shipping considerations, many

screen/tube assembly designs were limited to lengths that would fit in a standard shipping container.

128. These early designs used an eccentric method wherein the base pipe and other tubular components were positioned about different center lines to achieve the largest flow area for the transport tubes.

129. Packing tubes were typically smaller than transport tubes because they were dedicated to single screens and could tolerate higher friction. Shunt tubes were often rectangular to take advantage of the larger cross-sectional area they provided. 316L Stainless Steel was typically used due to its increased corrosion resistance. The junction between the transport tube and packing tube was typically in a "Y" configuration. The most common design was referred to as a "2×2" because it had two transport and two packing tubes with each packing tube tied to a transport tube.

130. Below, I provide other prior art disclosure of this eccentric 2×2 design by references Hurst (EX1013) and Hecker (EX1015):



EX1013 at Figs. 3 and 4; EX1015 at Fig. 3.

131. Hurst provided a history of the evolution of the Alternate Path system, including the rationale for making certain improvements and the benefits, disadvantages, and limitations of the system. EX1013 at 1. Certain disclosed improvements included (1) optimizing packing tube orifice diameter, (2) adding nozzles to prevent bridging and reduce leak-off, (3) increasing shunt tube diameter to increase flow area and reduce friction pressure drop, (4) moving from a general shunt tube with nozzles design to a packing and transport tube design for gravel packing to reduce friction and leak-off, (5) optimizing shunt tube diameter and length, and (6) modifying nozzle frequency. *Id.* at 1-4.

132. Hecker described technological improvements made on the "current eccentric 2×2 APT screens." EX1015 at 1. Hecker explained that the 2×2 eccentric system allowed for ensuring complete gravel packs beyond 400-ft intervals, with this system successfully gravel packing wells up to 3,200 feet in length at angles up to 93°. *Id.* at 2. However, field data indicated that this system was limited to packing 3,200-ft horizontals "due to the friction pressure associated with pumping through shunt tubes along the entire openhole interval," resulting in "[i]n-house best practices limit[ing] the shunt friction pressure to 3,000 psi to maintain reliability in the shunt packing system." *Id.*

5. Transition from Eccentric to Concentric Designs

133. In contrast to eccentric designs, a concentric orientation is one wherein the base pipe and other components are oriented about the same center line such that the space between the base pipe and the shroud is the same throughout.

134. In the '476 Patent, the concept of concentric transport and packing tubes was presented to showcase the round transport and packing tubes *"for withstanding higher pressures associated with greater depth wells."* EX1010 at 9:39-44 (emphasis added). The '476 Patent explained the benefits of the concentric shunt tube design along with manifolds at the entrance to each shunt tube assembly:

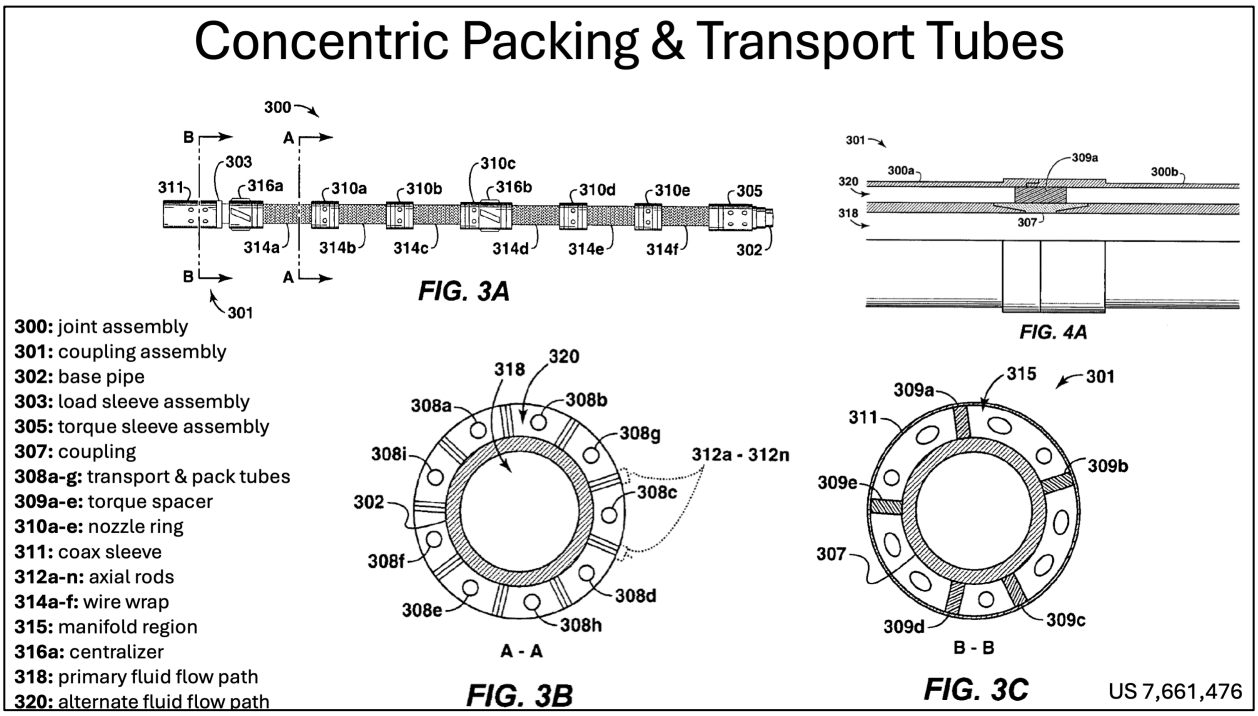
> Additional benefits of the present invention include the capability to increase the treatable length of alternate path systems

> from about 3,500 feet for prior art devices to at least about 5,000 feet and possibly over 6,000 feet for the present invention. This is made possible by at least the increased pressure capacity and frictional pressure drop of fluid flowing through the devices. Testing revealed that the joint assembly of the present invention is capable of handling a working pressure of up to about 6,500 pounds per square inch (psi) as compared to a working pressure of about 3,000 psi for conventional alternate path devices. The present invention also beneficially allow more simplified connection make-up at the rig site and decreases challenges associated with incorporating openhole zonal isolation packers into the screen assembly due to eccentric screen designs while limiting the exposure to damage of the shunt tubes, basepipe during screen running operations.

EX1010 at 23:41-57.

135. The ’476 Patent also disclosed that: “the tubes 308a-308i may preferably be constructed from steel, more preferably from lower yield, weldable steel. One example is 316L. One embodiment of the load sleeve assembly 303 is constructed from high yield steel, a less weldable material. One preferred embodiment of the load sleeve assembly 303 combines a high strength material with a more weldable material prior to machining. Such a combination may be welded and heat treated.” EX1010 at 9:46-53.

136. I reproduce Figures 3A-C and Figure 4A below for reference:

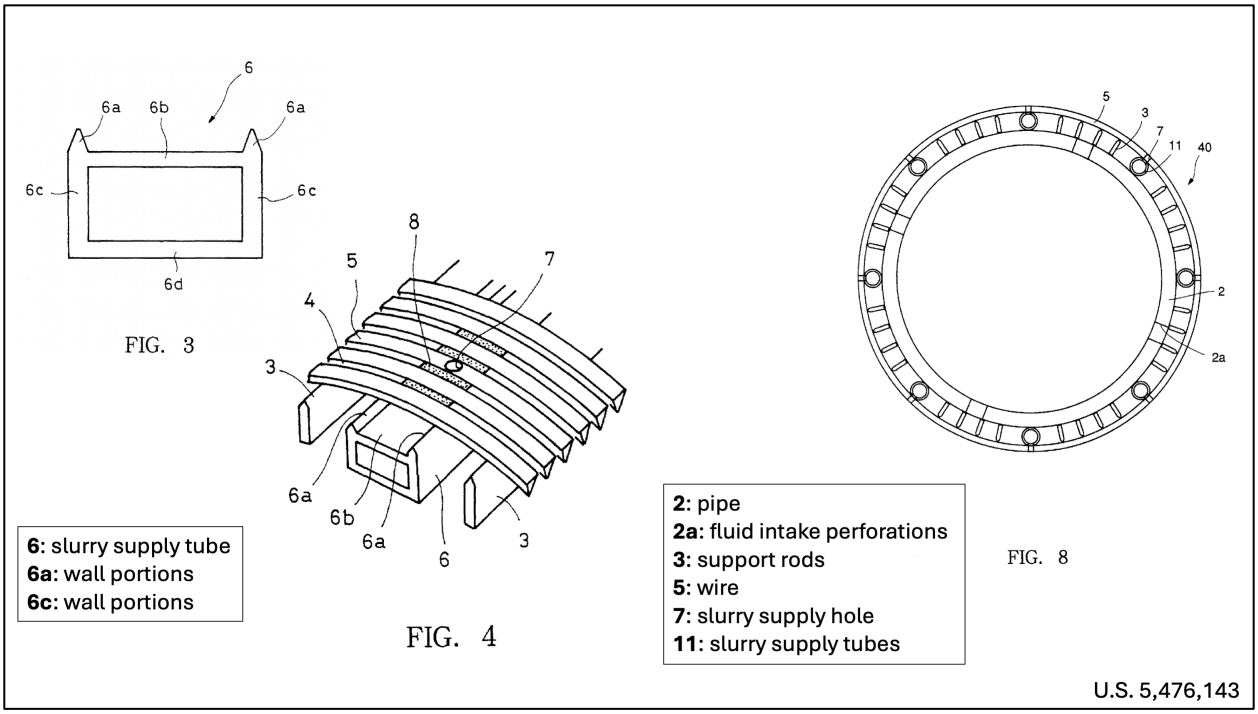


EX1010 at Figs. 3A-C, 4A.

137. Shunt tubes could be on the inside of the screens or on the outside of the screens. The examples in the ’476 Patent illustrated the shunt tube assembly positioned externally of the sand screen but taught that it “should be noted that in addition to the external shunt tubes shown in FIGS. 2A and 2B, which are described in U.S. Pat. Nos. 4,945,991 and 5,113,935, internal shunt tubes, which are described in U.S. Pat. Nos. 5,515,915 and 6,227,303, may also be utilized.” EX1010 at 7:44-48.

138. Shown below is a prior art example of concentric tube designs inside of screens from U.S. Patent No. 5,476,143 (“’143 Patent”) filed in April 1994, entitled

Well Screen Having Slurry Flow Paths, co-invented by Sparlin, Nagaoka, and Ashton and assigned to Nagaoka Int'l Corp. EX1023 at 1.



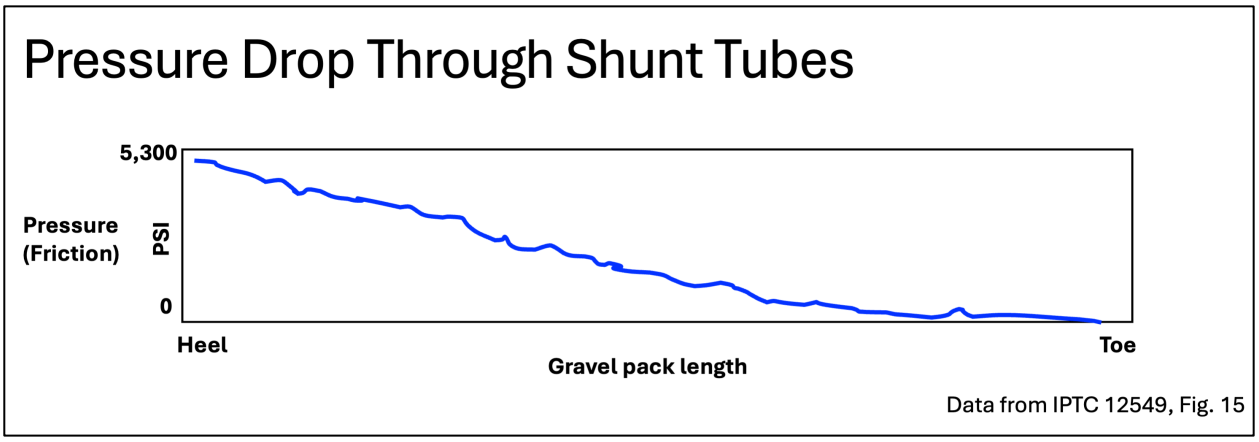
EX1023 at Figs. 3, 4, and 8.

6. Pressure Drop Through Tubes

139. It was well known that pumping gravel slurry through shunt tubes resulted in frictional pressures opposing the forced gravel slurry flow down the well. As assemblies grew in length, greater and greater entrance pressures were required to overcome the greater friction pressure drop through the shunt tubes.

140. This phenomenon was illustrated in Yeh2's Figure 15, which showed the pressure drop experienced in the transport tubes as gravel slurry traveled from heel to toe of a 5,000-feet long horizontal interval. EX1006 at 5, Fig. 15. This

pressure drop was primarily a function of the friction in the tubes. As will be discussed further, leak-off at orifices also influenced the amount and type of fluid as it was ever-changing from the heel to the toe of the well. Although the diagram below shows it to be horizontal, the same effect was seen in vertical or inclined wellbores. In Yeh2's example, at the heel of the well the pressure started at approximately 5,300 psi but steadily declined as it approached the toe of the well. It was common to pump at rates between one and eight barrels per minute ("bpm") with four to five bpm being the most common design pump rate. I provide a simplified rendering of these data in Figure 15 below:



See EX1006 at Fig. 15.

7. Shunt Tube Coupling

141. Shunt tube lengths are typically sized to cover a screen assembly of between 20' and 40' and are attached as an integral part of the gravel pack assembly. As mentioned previously, they can be attached on the inside or outside of the screen.

A common design is to attach a packing tube to a transport tube for each screen section.

142. The most common method is to connect only transport tubes between screen sections. This can be seen below as a direct coupling (like a "Y" configuration) or through a manifold, where the manifold is created at the point where the two screen sections are joined together. They may be the same size or different sizes. Typically, the entrances to the transport tubes are machined to allow a smooth transition and lower friction due to the higher flow volumes they typically employ.

143. The '476 Patent compared the six transport tubes in the new concentric design to a conventional 2×2 design: "Six 20 mm × 16 mm (OD×ID) shunt tubes yielded frictional response comparable to the two 1.5 × 0.75-in transport tubes in the current 'two-by-two' Alternate Path system." EX1010 at 24:14-17.

144. U.S. Patent No. 7,938,184 ("'184 Patent," EX1024) taught the importance of the shunt entry design in reducing pressure. "The transport conduits 508a-508*f* may also have ***a reduced entry pressure loss or*** smooth-profile design at their upstream opening to facilitate the fluid flow into the transport tubes 308a-308f. The smooth profile design preferably comprises a 'trumpet' or 'smiley face' configuration." EX1024 at 14:14-18 (emphasis added).

145. The '184 Patent was filed in November 2007, entitled *Wellbore Method and Apparatus for Completion, Production and Injection*, co-invented by Yeh, Haeberle, Barry, Hecker, Blacklock, Long, Brekken, Dybevik, Faret, Kvernstuen, Moen, Nesland, and Roaldsnes, and assigned to ExxonMobil Upstream Research Company. EX1024 at 1.

146. Shunt tube screen assemblies are typically manufactured as stand-alone components. Therefore, the systems to connect them must both employ a method to attach the inner base pipe and also a means to put the shunt tubes in a separate fluid communication. Many times, the application of this technology is offshore where rig time is extremely expensive. The original designs were very cumbersome and time-consuming. As lengths of completions in the industry grew, so did the pressure requirements. Torque requirements on connections have also increased. Therefore, much effort went into streamlining the process to make the connections more robust and more simply and quickly connected.

147. In the conventional 2×2 design, the tubes must be properly aligned, and jumpers installed.

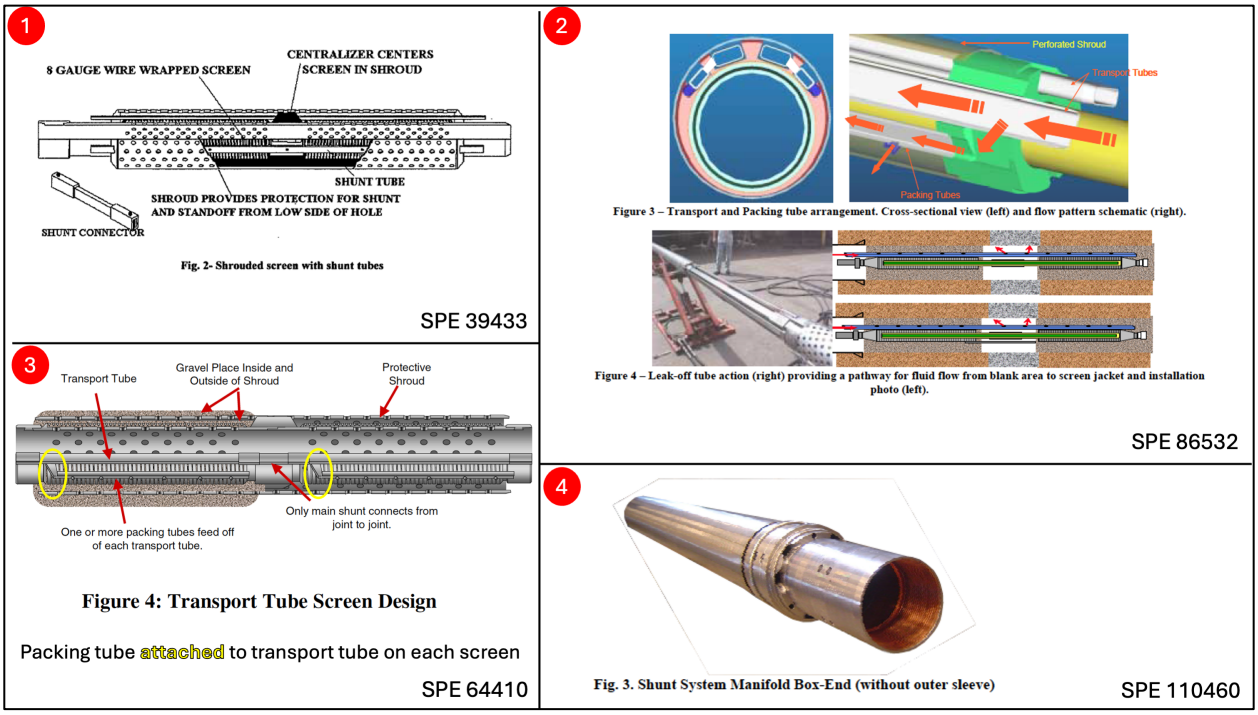
148. In manifold designs, the manifold is associated with the coupling of both an inner and outer connection to keep the two fluids separated. This typically requires less time to assemble but can be more expensive.

149. Below I provide a compilation of different shunt tube coupling systems known in the prior art. Example one is an illustration of a sand screen used in several gravel pack completions described in SPE 39433 ("'433 Paper," EX1025). The '433 Paper, published in 1998, entitled *Case History in Achieving High Rate Producers in Sub Sea Gravel Packed Completions*, was co-authored by Myers, Humphreys, Kaminski, Bouwaked, and Robertson, who were affiliated with SPE, Mobil Equatorial Guinea, Inc. or Mobil Technology Center. EX1025 at 1.

150. Example 2 is an illustration of the APT 2×2 design as disclosed in Hurst's Figures 3 and 4 (EX1013).

151. Example 3 depicts a shunt tube system from SPE 64410 Figure 4 (EX1026) wherein the packing tube was attached to a transport tube on each screen, which I indicated with yellow circles.

152. Example 4 provides a manifold system for coupling sand screen joints that was disclosed in Figure 3 of SPE 110460. This SPE paper was entitled *Openhole Gravel Packing with Zonal Isolation*, was published in 2007, and was co-authored by Barry, Hecker, Haeberle, Blacklock, and Yeh, who were affiliated with ExxonMobil Development Company or ExxonMobil Upstream Research Company. EX1027 at 1.



EX1025 at Fig. 2; EX1013 at Figs. 3 and 4; EX1026 at Fig. 4 (annotated); EX1027 at Fig. 3.

153. Patent Owner Halliburton also disclosed a process of coupling the screens and tubes in Bonner.

154. Bonner disclosed a shunt tube design, wherein the "main basis of design of the new system was to keep it functionally the same as existing industry-proven designs, in order to enjoy the empirical evidence of years of successful application of shunt tube gravel-packing technology." EX1016 at 2. Bonner considered "functionally the same" achieved:

> [I]f the flow areas for gravel packing slurry were essentially the same, the branching of flow to secondary tubes (packing tubes) from

> the primary flow tubes (transport tubes) was done in approximately the same manner, and the location and size of exit ports for flow to exit from the packing tubes were essentially the same. The mounting of the shunt tube system to each sand screen joint was designed in a common eccentric configuration, with the transport tubes brought into alignment at each joint connection via the use of an "oriented" premium thread.

Id. at 2.

155. Bonner's shunt tube assembly used the 2×2 eccentric configuration that was "used across the industry and has well known flow characteristics. [Bonner's] shunt tube system is using the same size, the same geometry of the transport and packing tubing, the same exit port spacing and arrangement…." *Id.* at 3. A cross-section of Bonner's shunt tube assembly is shown in Figure 5 below.

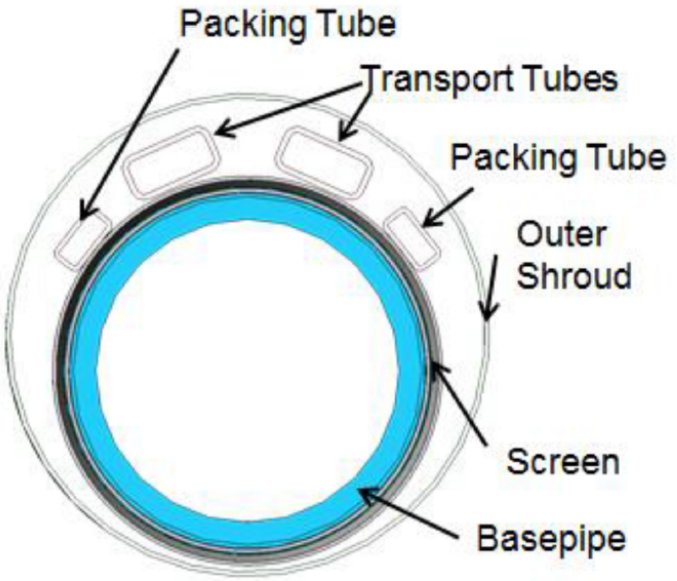


Figure 5—Cross section of shunt tube system

Id. at Fig. 5.

156. A side view of Bonner's shunt tube assembly was illustrated in annotated Figure 8 (below), wherein a box crossover (yellow box) connected a transport tube (**blue box**) to a packing tube (light blue box) that had nozzles, and a pin crossover connected a transport tube of one sand screen assembly to a jumper tube. *Id.* at Fig. 8; *see also id.* at 3 (explaining that the male end fitting of each jumper tube connected to the female end fitting of a transport tube at either end of each joint).

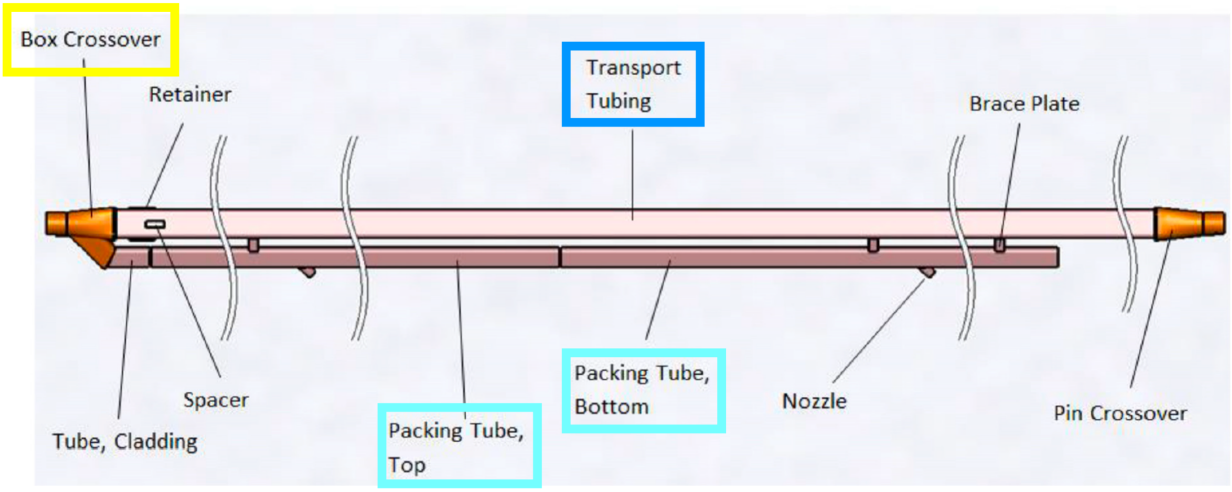


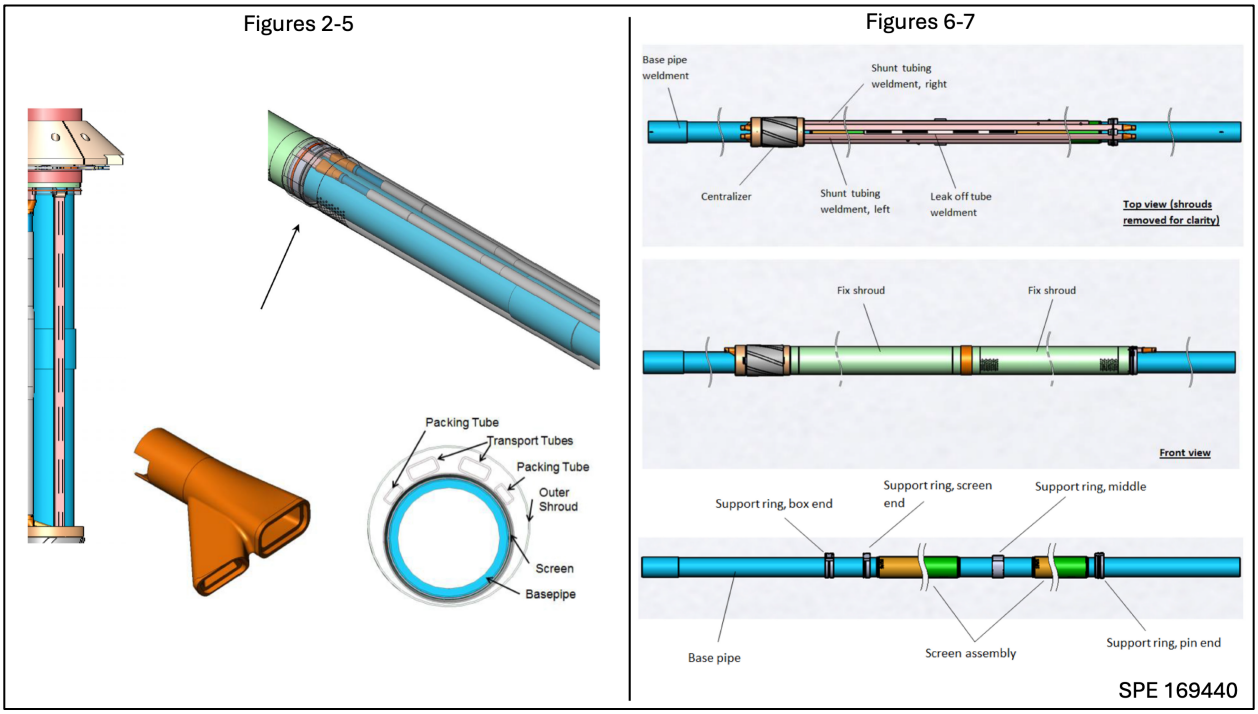
Figure 8—Shunt system tubing weldment with its components

Id. at Fig. 8 (annotated).

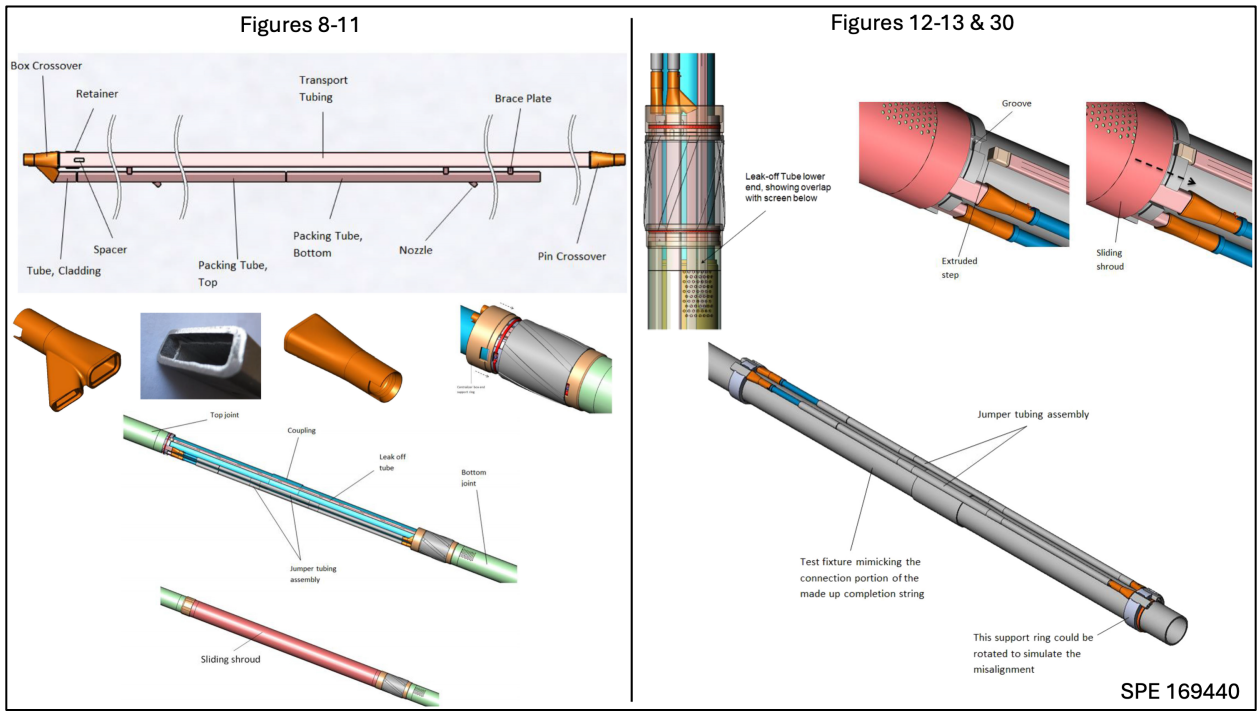
157. Bonner disclosed a considerable amount of testing was required to ensure the box crossover connection was robust enough to withstand higher pressures and forces of longer installations. *Id.* at 6-8, 11-13, 15-20.

158. Bonner also disclosed using centralizers to prevent the outer shroud from laying on the bottom of the well. *Id.* at 5. This is an important design consideration to ensure sand is placed 360 degrees around the screen. In the eccentric design it is possible to have the tubes only on the top as the sand screen rests on the bottom of a horizontal wellbore, and without centralizers, packing tubes only on the top would be unlikely to get 360-degree gravel coverage around the screen.

159. Below I provide a compilation of numerous figures disclosed in Bonner, illustrating its shunt tube system:



EX1016 at Figs. 2-7 (cropped).



EX1016 at Figs. 8-13, 30 (cropped).

8. Tube Shape

160. Tubulars may be of any shape. When referring to round versus rectangular tubes, U.S. Patent No. 5,890,533 ("'533 Patent," EX1028) disclosed round tubulars. The '533 Patent, entitled *Alternate Path Well Tool Having an Internal Shunt Tube* was filed in July 1997 and was invented by Jones and assigned to Mobil Oil Corporation. EX1028 at 1. The '533 Patent taught: "In order to keep the effective diameter of a tool as small as possible, external shunt tubes are typically formed from 'flat' rectangular tubing even though it is well. [sic] recognized that it is easier and substantially less expensive to manufacture a round tube and that a

round tube has a substantially greater and a more uniform burst strength than does a comparable rectangular tube." *Id.* at 2:1-7.

161. In 1991, the '796 Paper reported testing two sizes of round tubes (0.824" ID and 0.75" ID) and a rectangular 1"×0.5" tube. Shown in Table 1 below are the different tube sizes as well as 4 different hole sizes (1/16", 1/8", 3/16" and 3/32") as well as the hole density (spacing). When discussing the difference in diameter of the two round tubes Jones noted, "The small size variation did not alter results in any noticeable way." EX1009 at 2.

TABLE 1

Summary of ALLPAK™ Testing on Gravel Pack Simulator

Test	No. of Shunts (-)	Comments	Pack Type (-)	Shunt Size (in)	Hole Size (in)	Hole Density	Pack Efficiency (-)
1	0	w	circulation				75
2	2	w	circulation	0.824	3/16	2 per 1'	90
3	2	w	squeeze	0.824	3/16	2 per 1'	100
4	0	x	circulation				80
5	0		squeeze				70
6	2		circulation	0.75	1/8	1 per 1'	90
7	2		squeeze	0.75	1/8	1 per 1'	100
8	2	w	circulation	0.824	1/8	1 per 2'	95
9	2	x	circulation	0.824	1/8	1 per 2'	95
10	2	y	circulation	0.824	1/8	1 per 2'	95
11	0	z	sque-circ				65
12	4		circulation	1X0.5	3/32	1 per 2'	95
13	4		circulation	1X0.5	3/32	1 per 2'	98
14	4		sque-circ	1X0.5	3/32	1 per 2'	98
15	4	x,z	sque-circ	1X0.5	3/32	1 per 2'	99
16	4	z	circulation	1X0.5	1/16	1 per 4'	95
17	4	z	sque-circ	1X0.5	1/16	1 per 4'	95

Comments:
w - Run with 40#/1000 gal HEC gel
x - Run repeated with same result
y - Run with water and 4#/gal sand concentration
z - Run with 40/60 sand

Id., Table 1. Jones ultimately chose to use the rectangular tubes "to maximize the clearance in the annulus while still retaining substantial shunt tube cross sectional area for slurry delivery." *Id.* The original shunt tubes were 1" × 0.5"; however, the most common sizes used today reported by many authors for rectangular tubes are 1 ½" width by ¾" height for transport tubes and 1" width by ½" height for packing tubes. Jones' original rectangular tubes used 1/16" wall thickness as reported in U.S.

Patent No. 5,842,516 (EX1041), issued to Jones and assigned to Mobil Oil Corporation: "In well tools having alternate flowpaths such as that described above, the shunt tubes are typically formed from thin-walled (1/16 inch thick wall), steel conduit in order to keep the outer effective diameter of tool 20 small enough to allow the tool to be readily lowered into casing 13. While the conduit forming shunt tube 25 has been illustrated as having a rectangular cross-section, it should be recognized that conduits having other cross-sections (e.g. circular, etc.) can be used without departing from the present invention." EX1041 at 3:54-62.

162. By 2004, Hurst noted that the wall for rectangular tubes was 0.095" (*e.g.*, (0.75-0.56)/2 = 0.095). *See* EX1013 at 2 ("The tube dimensions were modified to 0.75×1.5-in external (0.56×1.31-in internal), yielding 3 times the flow area of the original design and reduction friction pressures over the rates of interest by approximately an order of magnitude, for long horizontal gravel packs."). Thus, Hurst noted an increase over the 0.0625" (1/16") wall of Jones' rectangular tube. Barry reported in SPE 110460 that using six round 20mm outer diameter shunt tubes with a 16 mm inside diameter, which he targeted for use in early 2008. EX1027 at 1, 3. Hecker reported in SPE 135102 that their concentric design was much easier to assemble than the conventional eccentric design. "A total of 57 connections were made up while running the ISAPT screen assembly and a peak run time of 10 joints

per hour was obtained. The make-up time is consistent with make-up times of conventional tubing and is a significant improvement over the five joints per hour average for the eccentric 2×2 design." EX1015 at 4.

9. Number of Tubes

163. There can be any number of tubes depending on the application. The most common current design for rectangular tubes is four with the 2×2 design using two transport tubes and two packing tubes. To gravel pack lengths of 400', it was common to have 4 tubes. For round tubes, the most common design is nine in a concentric arrangement, including six transport tubes and three packing tubes.

10. Metallurgy

164. Tubes, whether round, rectangular or other shape may be made of any material and size depending on the intended application. Carbon steel and stainless steel are the most common with 304 and 316L stainless being very common.

165. It is common for manufacturers to use corrosion resistant tube metallurgy like stainless steel because the screen assemblies may be stored in a non-climate-controlled warehouse and therefore would be subject to corrosion during storage. The tubes are isolated from the eventual production flow stream so corrosion resistance after installation is not a significant design consideration. Therefore, if corrosion resistance during storage is a significant design concern, then

chemical inhibitors can be used even on more corrosion prone materials like carbon steel.

166. One of the largest factors contributing to a tube's pressure rating or strength is its tensile strength. These pressure ratings and tensile strength ratings are well known and have been publicly available for purchase by the American Society for Testing and Materials ("ASTM") International for many years. A POSITA looking to determine the pressure or tensile strength ratings of metal to be used to manufacture tubing would know these ratings were available from the ASTM.

167. ASTM A554-16 Standard Specification for Welded Stainless Steel Mechanical Tubing provided standard specifications for austenitic, ferritic, and austenitic-ferritic duplex stainless steel mechanical tubing that was current as of 2016. EX1018 at 1. Table S2.1 showed that 304 L and 316 L stainless steel both had a tensile strength of 70 ksi (*i.e.*, kilopound per square inch, where one ksi = 1000 psi) or 483 MPa (*i.e.*, megapascals, where 1 MPa = 10^6 Pascals) and a yield strength of 25 ksi or 172 MPa. That these two types of stainless steel shared the same tensile and yield strengths indicated that the metallurgy could be changed from 316 L to 304 L without losing any strength. Below I provide Table S2.1 from the 2016 version of ASTM A554:

From *Standard Specification for Welded Stainless Steel Mechanical Tubing* (ASTM A554 – 16)

TABLE S2.1 Tensile Requirements (Round Annealed Condition)

Grade	Tensile Strength, min		Yield Strength, min		Elongation[A] in 2 in. or 50 mm, min, %
	ksi	MPa	ksi	MPa	
MT 429 and MT 430	60	414	35	241	20
MT-430-Ti	60	414	30	207	20
MT 304 L & MT 316 L	70	483	25	172	35

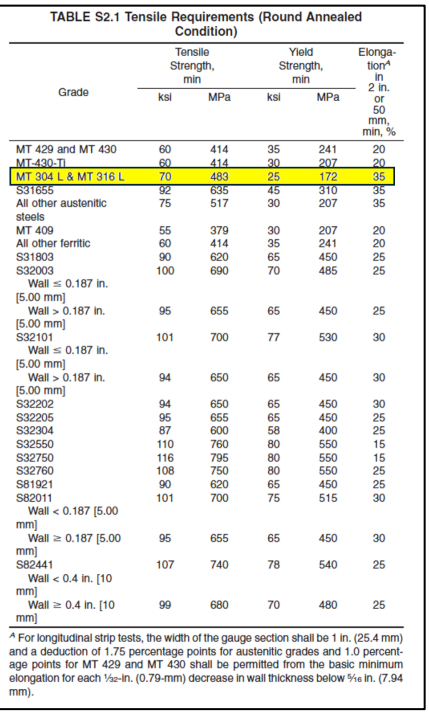


TABLE S2.1 Tensile Requirements (Round Annealed Condition)

Grade	Tensile Strength, min		Yield Strength, min		Elongation[A] in 2 in. or 50 mm, min, %
	ksi	MPa	ksi	MPa	
MT 429 and MT 430	60	414	35	241	20
MT-430-Ti	60	414	30	207	20
MT 304 L & MT 316 L	70	483	25	172	35
S31655	92	635	45	310	35
All other austenitic steels	75	517	30	207	35
MT 409	55	379	30	207	20
All other ferritic	60	414	35	241	20
S31803	90	620	65	450	25
S32003	100	690	70	485	25
Wall ≤ 0.187 in. [5.00 mm]					
Wall > 0.187 in. [5.00 mm]	95	655	65	450	25
S32101	101	700	77	530	30
Wall ≤ 0.187 in. [5.00 mm]					
Wall > 0.187 in. [5.00 mm]	94	650	65	450	30
S32202	94	650	65	450	30
S32205	95	655	65	450	25
S32304	87	600	58	400	25
S32550	110	760	80	550	15
S32750	116	795	80	550	15
S32760	108	750	80	550	25
S81921	90	620	65	450	25
S82011	101	700	75	515	30
Wall < 0.187 [5.00 mm]					
Wall ≥ 0.187 [5.00 mm]	95	655	65	450	30
S82441	107	740	78	540	25
Wall < 0.4 in. [10 mm]					
Wall ≥ 0.4 in. [10 mm]	99	680	70	480	25

[A] For longitudinal strip tests, the width of the gauge section shall be 1 in. (25.4 mm) and a deduction of 1.75 percentage points for austenitic grades and 1.0 percentage points for MT 429 and MT 430 shall be permitted from the basic minimum elongation for each 1/32-in. (0.79-mm) decrease in wall thickness below 5/16 in. (7.94 mm).

EX1018 at Table S2.1 (annotated and cropped).

168. ASTM A500/A500M-13 Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes provided standard specifications for cold-formed welded and seamless carbon steel that was current as of 2013. EX1029 at 1.

169. Table 2 of ASTM A500/A500M-13 showed a tensile strength of 62,000 psi (*i.e.*, 62 ksi) or 425 MPa and yield strength of 46,000 psi (*i.e.*, 46 ksi) or 315 MPa for Grade C carbon steel rectangular tubing. *Id.* at Table 2. I provide an annotated version of Table 2 below:

From *Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Round and Shapes* (ASTM A500/A500M – 13)

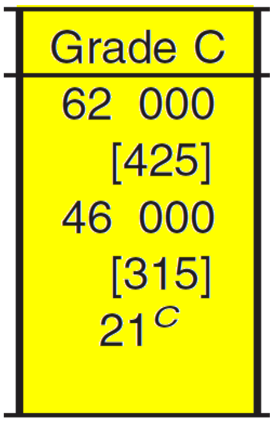


TABLE 2 Tensile Requirements

Round Structural Tubing	Grade A	Grade B	Grade C	Grade D
Tensile strength, min, psi [MPa]	45 000 [310]	58 000 [400]	62 000 [425]	58 000 [400]
Yield strength, min, psi [MPa]	33 000 [230]	42 000 [290]	46 000 [315]	36 000 [250]
Elongation in 2 in. [50 mm], min, %[D]	25[A]	23[B]	21[C]	23[B]
Shaped Structural Tubing	**Grade A**	**Grade B**	**Grade C**	**Grade D**
Tensile strength, min, psi [MPa]	45 000 [310]	58 000 [400]	62 000 [425]	58 000 [400]
Yield strength, min, psi [MPa]	39 000 [270]	46 000 [315]	50 000 [345]	36 000 [250]
Elongation in 2 in. [50 mm], min, %[D]	25[A]	23[B]	21[C]	23[B]

[A]Applies to specified wall thicknesses (t) equal to or greater than 0.120 in. [3.05 mm]. For lighter specified wall thicknesses, the minimum elongation values shall be calculated by the formula: percent elongation in 2 in. [50 mm] = $56t + 17.5$, rounded to the nearest percent. For A500M use the following formula: $2.2t + 17.5$, rounded to the nearest percent.
[B]Applies to specified wall thicknesses (t) equal to or greater than 0.180 in. [4.57 mm]. For lighter specified wall thicknesses, the minimum elongation values shall be calculated by the formula: percent elongation in 2 in. [50 mm] = $61t + 12$, rounded to the nearest percent. For A500M use the following formula: $2.4t + 12$, rounded to the nearest percent.
[C]Applies to specified wall thicknesses (t) equal to or greater than 0.120 in. [3.05 mm]. For lighter specified wall thicknesses, the minimum elongation values shall be by agreement with the manufacturer.
[D] The minimum elongation values specified apply only to tests performed prior to shipment of the tubing.

Id. at Table 2 (annotated and cropped).

170. The 425 MPa tensile strength for carbon steel compares favorably to the 483 MPa for 316 L stainless steel. Therefore, it is my opinion that carbon steel may be a good, less costly substitute for 316 L stainless. Stainless steel has a higher tensile strength, but the yield strength is about half that of carbon steel (172 MPa for stainless versus 315 MPa for carbon), making stainless a much softer material. Therefore, while stainless steel has better corrosion resistance, it would have less erosion resistance (because it is softer). Ultimately, a POSITA would make material selections based on many factors, such as cost, strength, availability, welding ability,

etc., and corrosion and erosion resistance, all of which were well understood in June 2018.

171. In the '184 Patent, Yeh taught the importance of selecting the proper metallurgy and heat treating of the tubes:

> As shown in FIG. 3B, in some embodiments of the present techniques, the ***transport and packing tubes*** 308a-308i, (although nine tubes are shown, the invention may include more or less than nine tubes) preferably have a ***circular cross-section for withstanding higher pressures associated*** with greater depth wells. The transport and packing tubes ***308a-308i*** may also be continuous for the entire length of the joint assembly ***300.*** Further, the tubes ***308a-308i*** may ***preferably be constructed from steel, more preferably from lower yield, weldable steel***. One example is 316L. One embodiment of the load sleeve assembly ***303*** is constructed from high yield steel, a less weldable material. One preferred embodiment of the load sleeve assembly 303 combines a high strength material with a more weldable material prior to machining***. Such a combination may be welded and heat treated***. The packing tubes 308g-308i (although only three packing tubes are shown, the invention may include more or less than three packing tubes) include nozzle openings 310 at regular intervals, for example, every approximately six feet, to facilitate the passage of flowable substances, such as a gravel slurry, from the packing tube 308g-308i to the wellbore 114 annulus to pack the production interval 108a-

> 108n, deliver a treatment fluid to the interval, produce hydrocarbons, monitor or manage the wellbore. Many combinations of packing and transport tubes 308a-308i may be used. An exemplary combination includes six transport tubes 308a-308f and three packing tubes 308g-308i.

EX1024 at 10:66-11:26 (emphasis added).

172. Jones (the ’991 Patent) explained metallurgy and shape: “Conduit 28 can consist of a pipe (either circular, square, rectangular, or curved, etc.) with perforations 30, or lateral conduits 32 to permit flow or slurry gravel pack into annular section 20. Although the conduit 28 may be made of ***any pressure-resistant material*****,** it is preferably to be made of stainless steel.” EX1007 at 4:7-13 (emphasis added).

11. Maximum Pressure

173. Tubes come in various sizes, metallurgy, and wall thicknesses all of which determine the maximum allowable pressure. For round tubes the math is fairly straightforward as burst is typically a function of the stress yielding of the material. However, for rectangular tubes in most applications the material is allowed to yield and change its shape before failing. The way it is installed in the screen assembly can limit the yield and shape of the rectangular tubing to provide additional support, so laboratory testing is normally performed to determine the maximum rated pressure for rectangular tubes.