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3,552,779

DUAL-CONDUIT DRILL PIPE FOR EARTH BORING

Filed May 31, 1968

3 Sheets-Sheet 1

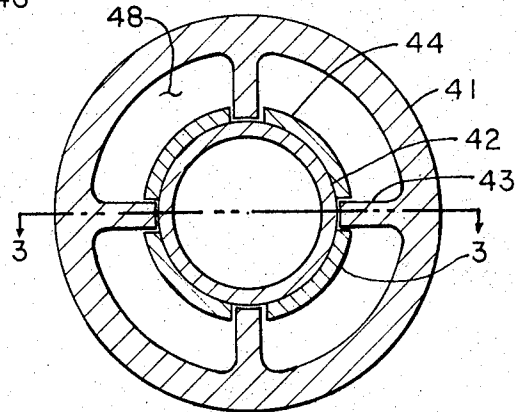
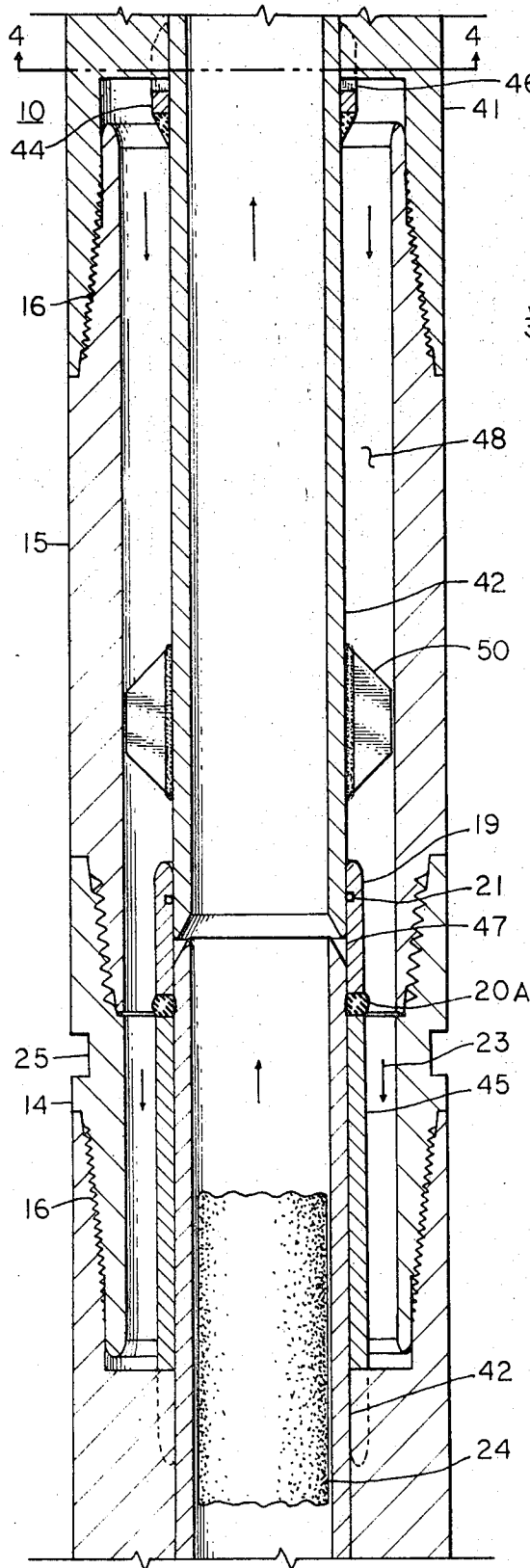


FIG. 4

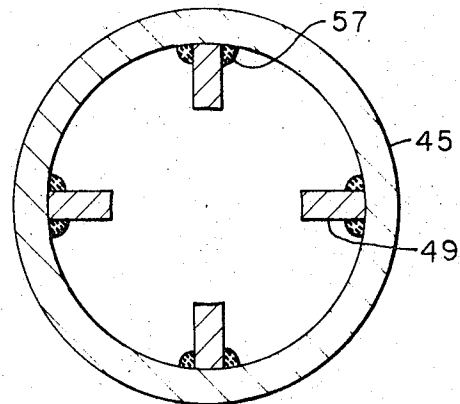


FIG. 5

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DUAL-CONDUIT DRILL PIPE FOR EARTH BORING

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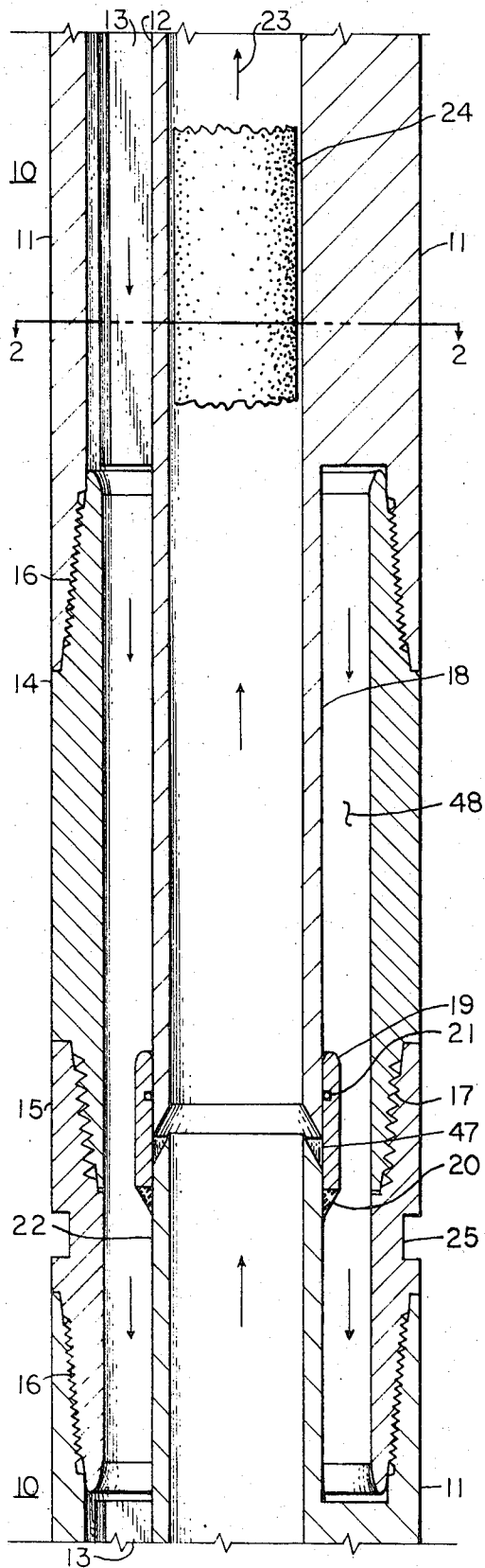


FIG. 1

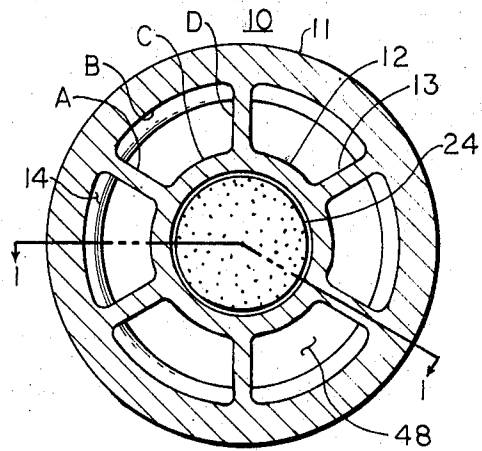


FIG. 2

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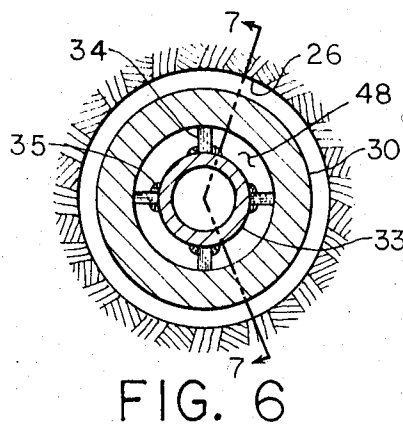
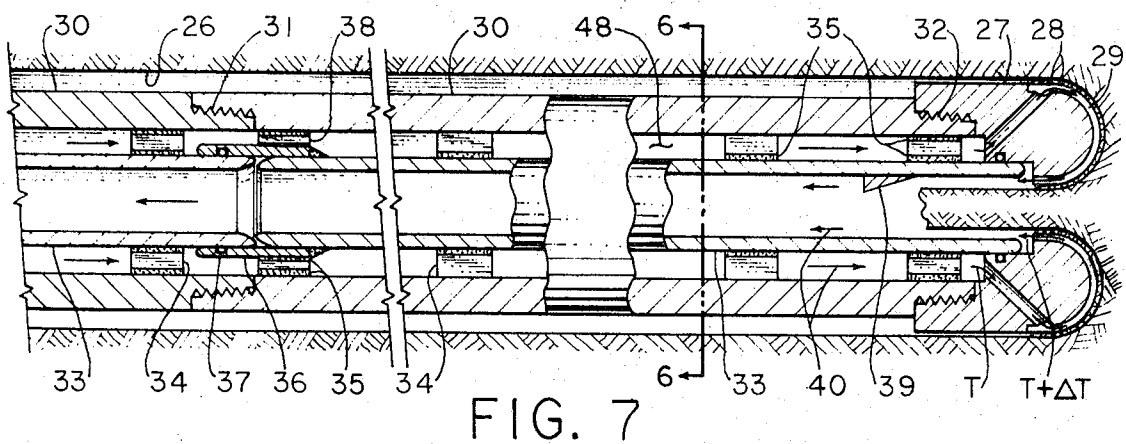
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DUAL-CONDUIT DRILL PIPE FOR EARTH BORING

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3 Sheets-Sheet 3



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DUAL-CONDUIT DRILL PIPE FOR EARTH BORING

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2 Claims

ABSTRACT OF THE DISCLOSURE

A dual-conduit drill pipe comprising individual "lengths," or "joints," which "lengths" are permanently assembled components forming dual longitudinal passages, or conduits, and which "lengths" are adapted to be threadedly connected, one to another, to form a "string" of dual-conduit drilling pipe. One object of the invention is to solve the high thermal stress problem due to differential thermal expansion experienced in dual-conduit drilling operations, wherein the fluid in one conduit may be at a considerably higher temperature than the fluid in the other conduit. For shallow drilling this is herein accomplished by extruding a dual-conduit section of a soft, low strength aluminum alloy, with the high thermal conductivity of the aluminum alloy providing a heat exchange factor sufficient to reduce the differential temperature and hence the thermal stress to safe values. Intermediate depth drilling requires higher strength aluminum alloys, and these cannot be extruded in such a full section, multiple-void, hollow-shape and consequently two extrusions are made and assembled by welding in such a manner as to provide for limited, relative longitudinal movement and expansion of the inner tube. Deep drilling requires a high strength, high hardness aluminum alloy and such an alloy can be extruded only as cylinders, or tubes, at this stage of the extrusion art. Consequently, for deep drilling the outer tube has welded thereto longitudinal, inwardly projecting, fins to space and retain the inner tube and to provide for relative longitudinal movement and expansion. For extreme depth drilling the latter construction can be of steel. The lightness of aluminum is desirable in a drill pipe, in all respects except for imposing weight on the drill bit. To solve this shortcoming, there is a disclosed, special, heavy, dual-conduit drill pipe of steel, that is immune to buckling when caused by minor differential thermal expansion, found at the bottom of the hole.

For purposes of simplicity and clarity a dual-conduit drill pipe may be considered as comprising two main portions; an outer tube, and a concentric inner tube with the annulus between the tubes forming one flow conduit, and the bore of the inner tube the second flow conduit. The outer tube having a heavier wall than the inner-tube, and designed to take the strains of torque and tension imposed by drilling processes. It is often termed the "drill tube". The inner tube is often termed the "core tube" inasmuch as its main function is to provide an inner flow conduit for the drilling fluid to return to the earth's surface and thereby transport the bit cuttings, and, or cores, to the earth's surface.

Earth boring with multiple-conduit drill pipe has been attempted and practiced for several decades. Still, however, there is no satisfactory drill pipe. The first attempts were with multiple concentrically assembled tubes, rigidly connected one to the other. It was found in drilling that the difference in temperature of the descending fluid and ascending fluid, caused a similar difference of temperature in the walls of the conduits, and consequently differential thermal expansion (or contraction) resulting in thermal stresses sufficient to bend the as-

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sembly, resulting in flexing of the drill pipe, and causing crooked holes, stuck pipe, and pipe failures.

Attempts have been made in dual-conduit pipe, as in applicant's Pat. No. 3,208,539, to use an outer tube and a concentric inner tube spaced with spacing fins welded on the inner tube and with one end of the inner tube rigidly secured to said outer tube by welding and the other end engaging a sealing sleeve of the mating length of pipe, with said unwelded end free to expand and contract thermally in said sleeve. This was a partial solution of the problem, but left several unsatisfactory conditions: (1) To get the spacing fins into, or out of, the outer pipe it was necessary to use internal flush pipe which is prohibitive with practical wall thicknesses because of weakness at the joints. (2) For long life drill pipe it is essential to use thick-wall tool joints. Attempts have been made to use such by substituting spacing springs for the spacing fins, but vibration plus galvanic corrosion of the inner pipe has resulted in early failure of the springs and inner tube. (3) It has been found impractical to securely weld the spacing fins at one end to the inside of the outer pipe. (4) It has been found that due to corrosion and abrasion that several thin-walled inner tubes will fail during the life of an outer tube, and that inner tube removal and replacement is difficult and expensive.

One object of this invention is to provide a dual-conduit drill pipe in which the heat exchange coefficient between the walls of the two conduits is sufficiently high, so that in normal drilling the temperature difference of fluid in the two conduits is reduced to where the differential thermal stress in the conduit walls is sufficiently low as to be tolerable.

Another object of this invention is to provide a dual-conduit drill pipe connected by relatively thick-walled steel tool joints.

Another object of this invention is to provide a dual-conduit drill pipe wherein the inner core tube shares the tensional stress when excessive tensional strain is put on the outer drill pipe.

An object of the invention is to provide a dual-conduit drill pipe wherein the inner tube can be removed, and replaced, with facility in the field, and without any dismantling or damage to the outer pipe or tool joint.

A further object of the invention is to provide dual-conduit drill pipe wherein the inner tube is free to move longitudinally, and expand or contract, relative to the outer tube, within limits.

Still a further object of the invention is to provide a heavy, warp-resisting, all-steel, dual-conduit drill collar to put weight on the drill bit when used in conjunction with aluminum dual-tube drill pipe.

Another object of this invention is economy. By extruding the full section of the drill pipe, or just the outer tube and fins, a big reduction in shop time and expense is effected, reducing considerably the per foot cost of dual-conduit pipe.

Another object of this invention is to provide a dual-conduit drill pipe that is relatively light in weight to facilitate handling and to increase the maximum length of pipe that a given drill rig can handle.

Other objects and advantages of this invention will become apparent from the description with the accompanying drawings wherein:

FIG. 1 is a longitudinal vertical sectional view taken on line 1—1 of FIG. 2, and is an embodiment of this invention adapted for shallow depth drilling.

FIG. 2 is a sectional view taken on line 2—2 of FIG. 1. FIG. 3 is a longitudinal sectional view, taken on line 3—3 of FIG. 4, and is an embodiment of this invention adapted for intermediate depth drilling.

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FIG. 4 is a sectional view taken on line 4—4 of FIG. 3.

FIG. 5 is a cross sectional view of an embodiment of this invention adapted for deep drilling.

FIG. 6 is a cross sectional view of a dual-conduit drill collar, adapted for this invention. The section was taken on line 6—6 of FIG. 7.

FIG. 7 is a longitudinal sectional view taken on line 7—7 of FIG. 6.

The preferred embodiment of this invention for shallow drilling is shown in FIG. 1 and FIG. 2. The dual-conduit drill pipe 10 is an aluminum alloy extruded as a multi-void, hollow-shape as shown by FIG. 2. This aluminum alloy may be 6063-T6, with a tensional yield strength of 31,000 p.s.i. and a hardness of 80 BHN. The length of these extrusions is normally determined by the length of the drill's mast and, whether or not, the drill pipe is handled manually. The ends of the outer tube 11 are cut to length and internally threaded to receive their respective sections of the steel tool joints, box 14, and pin 15, as shown in FIG. 1. The upper end of the inner tube (core tube) 12 is cut to length as shown by 22, and the end chamfered. A sleeve 19, carrying an O-ring 21 is fitted on the upper end of 22 and welded as at 20. The sleeve 19 may be placed at either end of the inner tube, if so elected, but the election cannot be varied in a single drill pipe string. The lower end of the core tube 12 is cut to length as at 18 and the end is internally tapered as shown. A small gap 47 is left between the ends of the core tube segments 18 and 22 to provide for shop error and differential thermal expansion between the aluminum segments 18 and 22, and the steel joints 14 and 15. The steel tool joints are conventional. The threads 16 may be coated with epoxy cement just prior to make-up, to assure that this threaded connection will not loosen in service. This connection can be broken if heated moderately. The arrows 23 show the direction of fluid flow. A core rising in the core tube is shown at 24.

It will be seen that these lengths can be assembled, as in FIG. 1, to form a string of dual-conduit drill pipe. The drilling fluid descends in the tube annulus 48 between the outer tube 11 and the inner tube 12. The drilling fluid ascends within the core tube 12.

Upon examination of the cross section FIG. 2, it will be recognized that this dual-conduit is an excellent counter-flow heat exchanger. The surfaces A, B, C, D, FIG. 2, are all at the same temperature, the temperature of the turbulently flowing fluid in this annulus. This large surface area of equal temperature tends to stabilize distortion of the drill pipe due to differential thermal expansion.

The thermal conductivity of aluminum, at the temperatures involved, averages 118 B.t.u./hr./sq. ft./degree F./foot of thickness; while the conductivity of steel is 26 B.t.u. The ratio of these conductivities:

$$\frac{118}{26} = \frac{4.54}{1}$$

This is one big advantage when using aluminum instead of steel, for dual-tube drill pipe. A second reason based on the physical properties is the specific weights: steel is 0.283 lb., while aluminum is 0.100 lb., both per cu. in., and the ratio is 1/2.83, therefore aluminum pipe is a great favorite with men who must handle drill pipe.

The analysis of the differential thermal expansion stresses for dual-tube drill pipe is best made by starting at the bottom of the bore hole, where the temperature differential is known. Referring now to FIG. 7, which is drill collar on the bottom of the hole. The arrows 40 indicate the fluid flow direction, down in the tube annulus 48, and up in the core tube 33. Consider the section just above the bit, where the fluid in the annulus is just entering the bit nozzle and is at some temperature T. After this fluid has passed through the bit and is entering the core tube, it has an increased temperature

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$T + \Delta T$ due to the fluid friction in the nozzles and the bit passages.

When drilling with water, and with a $4\frac{1}{2}$ inch O.D. drill pipe, it is customary to circulate 2 bbl./min., and the pressure drop across the bit is then normally 100 p.s.i. the hydraulic horsepower of this bit flow:

$HP = \text{g.p.m.} \times \text{p.s.i.} / 1714 = 84 \times 100 / 1714 = 4.9 \text{ HP}$
1 HP is equivalent to 42.44 B.t.u./min., and 4.9 HP = 208 B.t.u./min. Assume that all of this energy went into heating the fluid (which it does not). A flow of 2 bbl./min. is 700 lbs. of water/min. One B.t.u. is defined as that quantity of heat required to raise the temperature of 1 lb. of water 1°F . Therefore the temperature rise in the water:

$$\frac{208}{700} = 0.297 \text{ B.t.u./lb. or } \Delta T = 0.297^\circ \text{F.}$$

Such a small temperature differential will cause insignificant stress in the pipe. The temperature differential continues to increase, however, as the fluid in the core tube moves upward since the earth's temperature gradient is approximately $1^\circ \text{F./100 ft.}$ When the fluid has moved upward 1000 ft., it is positioned where the earth's temperature is 10°F. cooler than at the bottom of the hole. For simplicity, assume that the fluid in the pipe annulus at that point is also 10°F. cooler than at the hole bottom. The error due to this assumption is on the safe side as tests have shown that when drilling the fluid never reaches a temperature as high as the temperature of the formations, because of the low coefficient of heat conduction of the earth's formations. If the fluid is allowed to remain static in the hole for several days, then it does reach formation temperature. In practice the fluid velocity in the core tube is 7.2 ft. sec., or 430 ft./min. The mass flow rate is 700 lbs./min. It is desired to find the required differential temperature across the core tube which will assure that the differential temperature between up-flowing and down-flowing streams will be constant. That is, the up-flowing stream will lose heat to the down-flowing stream equivalent to $1^\circ \text{F./100 ft.}$ A normal core tube for $4\frac{1}{2}$ in. drill pipe is: O.D. = 2.500 in. I.D. = 2.187 in. and wall thickness = .156 in. The following formulas are from Mark's Mechanical Engineer's Handbook, 6th ed., pp. 4-100 and ff: $q = UA(\Delta T)_m$ where q = rate of flow, B.t.u./hr., U = the over-all coefficient of heat transfer; B.t.u./hr. sq. ft./ $^\circ \text{F.}$; A = area in sq. ft.; $(\Delta T)_m$ = the logarithmic means of the temperature difference. To evaluate

$$UA: -\frac{1}{UA} = \frac{1}{h_i A_i} + \frac{x}{KA_m} + \frac{1}{h_s A_s} + \frac{1}{h_o A_o}$$

where $1/h_i A_i$ is the thermal resistance of the liquid film at the hot surface; $1/h_o A_o$ is the thermal resistance of the liquid film at the cold surface; X/KA_m is the resistance of the metal of the tubular wall; $1/h_s A_s$ is the resistance of the scale deposit on the walls. The expressions:

$$\frac{1}{h_i A_i} + \frac{1}{h_o A_o}$$

can be combined to $1/h_m A_m$. Where h_i is the coefficient of heat transfers of the hot side film; h_o is the coefficient of heat transfer of the cold side film; h_m is the mean average of h_i and h_o ; A is the area (sq. ft.) of each quantity, h_s is the coefficient of heat transfer of the scale deposit; X is the thickness of metal wall in feet; and K is the coefficient of conductivity of the metal.

With an aluminum core tube of the above dimensions, and 100 ft. long:

$$\frac{1}{UA} = \frac{1}{h_m A_m} + \frac{1}{h_s A_s} + \frac{X}{KA_m} = \frac{1}{49,600} + \frac{1}{33,500} + \frac{.013}{7,200} = .0000517$$

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$$\therefore UA = 19,300 \text{ B.t.u./hr. through 100 ft. of tube/1}^\circ \text{ F.}$$

$$q = UA(\Delta T) = 19,300(\Delta T) \text{ B.t.u./hour}$$

$$= 322(\Delta T) \text{ B.t.u./min.}$$

In one minute 700 lb. of new water comes into this 100 ft. section and 700 lbs. leaves it. If this 700 lbs. is to lose sufficient heat to reduce its temperature 1° F. then 700 B.t.u. transfer is required/min. Therefore:

$$q = 700 = 322(\Delta T) \text{ and } \Delta T = \frac{700}{322} = 2.2^\circ \text{ F.}$$

This indicates that as the fluid in the aluminum core tube moves upwardly from the bit, it soon reaches a point where it is 2.2 hotter than the fluid in the pipe annulus at the same horizon, and continues to lose heat at a rate to retain this temperature differential as it moves up the hole.

To determine if such a differential temperature is structurally dangerous, we use the formula $S = CE(\Delta T)$ where S =stress, p.s.i., C =temperature coefficient, and ΔT is in $^\circ \text{ F.}$ For aluminum:

$$C = .000013, E = \text{Young's modulus} = 10 \times 10^6 \text{ p.s.i., and } \Delta T = 2.2^\circ \text{ F.}$$

$$\text{Stress} = S = .000013(10 \times 10^6)2.2 = 286 \text{ p.s.i.}$$

The formula for allowable stress on an aluminum column from Roark's "Formulas for Stress and Strain," 3rd ed., p. 238:

$$\text{Allowable stress} = S = \frac{102,000,000}{[.75L/r]^2}$$

where L =column length in inches (assume each length to be 30 ft.), r =radius of gyration, in.

$$S = \frac{102,000,000}{[.75(360)/.83]^2} = 961 \text{ p.s.i.}$$

as allowable stress. This gives a factor of safety of

$$\frac{961}{286} = 3.4 \text{ to } 1$$

Actually the factor of safety is larger than this since the beneficial heat conduction of the webs was not considered, for simplification reasons.

The extruded section, being integral, with full length web, has a section modulus greater than the section shown in the above patent.

FIG. 3 and FIG. 4 show a modification of this invention for moderate depth drilling. Due to the increase in depth, it must use an aluminum alloy of higher strength. By simplifying the extrusion section of FIG. 2 to that of FIG. 4 the aluminum alloy 6061 can be successfully extruded. It has a yield strength of 40,000 p.s.i., a 29% increase over the strongest alloy extrudable in the section of FIG. 2. In this modification a separate core tube 42 is used. A positioning sleeve 44, slotted to receive the webs 43 is welded onto this tube as shown. The core tube 42 is then inserted in the cavity left by the radial webs 43, and on the opposite end of the core tube is welded another positioning sleeve 45, also slotted to receive the webs 43. The sleeve 45 and the sealing O-ring sleeve 19 may both be welded to the core tube 42, as shown at 20A. It will be seen that in no place is the core tube welded to the drill tube 41 or the fins 43. The core tube 42 is free to move longitudinally relative to the outer tube 41, within limits. The gap 46 permits that amount of stretch of the drill tube 41 without subjecting the thin core tube 42 to stress. Since the fins are on the drill tube 41, they share in the tension load and after they contact the sleeve 44, the core tube must also share the load, which is highly desirable. In some areas where tension loads are severe, it may be desirable to reduce the length of the gap 46, even to zero. The gap 47 permits the core tube to lengthen thermally relative to drill tube 41. The weld 20A is near the open end of the tool joint box 14, so that it is accessible and easily welded in the field, and just as easily cut out for field replacement of the core tube. It will be observed that the core tube is

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free to thermally extend or contract. In normal drilling the fluid in the core tube is always hotter than the fluid in the tube annulus 48, and any differential temperature results in a relative lengthening of the core tube, and this increase in length is accommodated by the tolerance gap 47.

The groove 25 in the tool joint is to receive a special elevator which elevator has an inwardly protruding flange to engage this groove.

For deep drilling the hardest and strongest possible aluminum alloy is desired, such as the 7075 alloy used in conventional drill pipe (yield strength 72,000 p.s.i.). Even the simple section of FIG. 4 cannot be extruded using this alloy and a simple tube 45 must be substituted therefore. In this case I prefer to carefully shop weld 57 the webs 49 onto this tube 45 as shown in FIG. 5, otherwise the construction is as shown in FIG. 3. It is preferable that these webs extend the full length of the drill tube 45 like those shown in FIG. 3. These fins can be resistance welded, or flash welded, or they can be edge welded, or, at intervals the tube 45 can be drilled and the fin and tube plug welded. Short segments of the full length webs 49, welded at each end will suffice, but some vibration of fins and core tube 42, will result in premature failure. Even an all steel construction can be used in the construction of FIG. 5 by providing sufficient gap spaces 46 and 47. The fans 50, are for centering.

In all drilling it is desirable that the drill pipe be free from compression. This is especially true of aluminum drill pipe. To assure that the drill pipe will be free of compression, a section of heavy, steel, dual-conduit drill pipe (normally termed "drill collar") as shown in FIGS. 6 and 7, should be used with aluminum drill pipe to provide all the weight to be needed on the bit. This is quite similar to the drill pipe of my patent, cited above, except the outer tube 30 is exceedingly heavy. Much too heavy to be practical for drill pipe. This heavy construction has a three-fold purpose: (1) to provide as much weight as feasible per foot of length; (2) to provide sufficient metal in the drill tube 30 so that there is not undue weakness at the threads 31; (3) to assure that any stress in the thin-walled core tube 33, does not distort the thick-walled drill tube 30.

As discussed above, the temperature difference, between the pipe annulus fluid and the core tube fluid, at a point just above the bit is approximately 0.3° F. This is a negligible amount. As a consequence the core tube 33 can be rigidly connected at both its ends, to the drill tube 30, as shown at 35 and 38. This practice can be continued even though there be 200 feet of drill collar, since the temperature differential at the top (200 feet above the bit) is only $2 + 0.3 = 2.3^\circ \text{ F.}$ It will be noted in FIG. 6 that the volume of metal in the drill tube 30 is many times the volume of metal in the core tube. The stress in the steel core tube with a temperature differential of 2.3° F. , is:

$$S = CE(\Delta T)$$

$$\text{Stress} = S = (6.5 \times 10^{-6})(30 \times 10^6)2.3 = 450 \text{ p.s.i.}$$

assuming that the core tube is completely contained. Such a stress is negligible for this combination, because the heavy-walled drill tube 30 dominates the thin-walled core tube 33. The stiffness modulus of a tube is proportional to the product EI where E is Young's modulus, and I the moment of inertia. If the core tube in the drill collar has dimensions: 2.375 inches O.D. x .120 inch wall thickness, its moment of inertia is 0.542 inches⁴. The outer tube dimensions may be: 4.50 inches

$$\text{O.D.} \times 0.674$$

inch wall thickness with a moment of inertia=15.28 inches⁴. The ratio of the stiffness modules of these two tubes:

$$\frac{E(0.542)}{E(15.28)} = \frac{1}{28.2}$$

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Hence, it is obvious that a thermal stress of 450 p.s.i. in the inner tube will not cause measurable deflection of the outer tube, and that an all-welded rigid construction is feasible near the bottom of the hole. It is important that the fins 34, welded to the inner tube 33, be of such a width as to snugly fit the inner walls of the outer tube 30, and that they be spaced at short intervals, to prevent vibration of the tube 33, and to prevent eccentricities and/or deflections that might result in wrinkling the thin walls of the stressed tube 33.

Although I have described my invention with a degree of particularity, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and scope of the invention as hereinafter claimed.

Having described my invention, I claim:

1. In a dual-conduit drill pipe comprising an outer tube, an inner tube, support means concentrically supporting the said inner tube within the said outer tube, the annulus between said tubes forming one flow conduit, the bore of said inner tube forming a second flow conduit, a box tool joint on one end of the said outer tube and a pin tool joint on the opposite end of the said outer tube threadedly and sealably connecting lengths of like said dual-conduit drill pipe when in a string of such pipe, said inner tube having a sealing sleeve on one characteristic end, said sealing sleeve sealingly engaging the non-characteristic end of the inner tube of the adjacent length of like pipe when in a connecting string, the improvement comprising:

said outer tube having longitudinal webs extending ra-

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dially inward to the surface of the said concentric inner tube,

said webs slidably supporting said inner tube, said inner tube having secured on each end thereof, positioning sleeves that are axially slotted to slidably receive the ends of said webs,

said slotted sleeves engaging said webs thereby preventing the said inner tube from rotating relative to said outer tube and limiting the longitudinal movement of the inner tube relative to the outer tube.

2. The drill pipe defined by claim 1 wherein:

the said outer tube, said inner tube, and said webs are made of aluminum metal.

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U.S. Cl. X.R.

285—333