Feb. 1, 1955 D. B. GRABLE 2,701,122

METHOD AND APPARATUS EMPLOYING COMPRESSED GAS FOR DRILLING WELLS

Filed Aug. 25, 1951 2 Sheets-Sheet 1

Fig. 1.

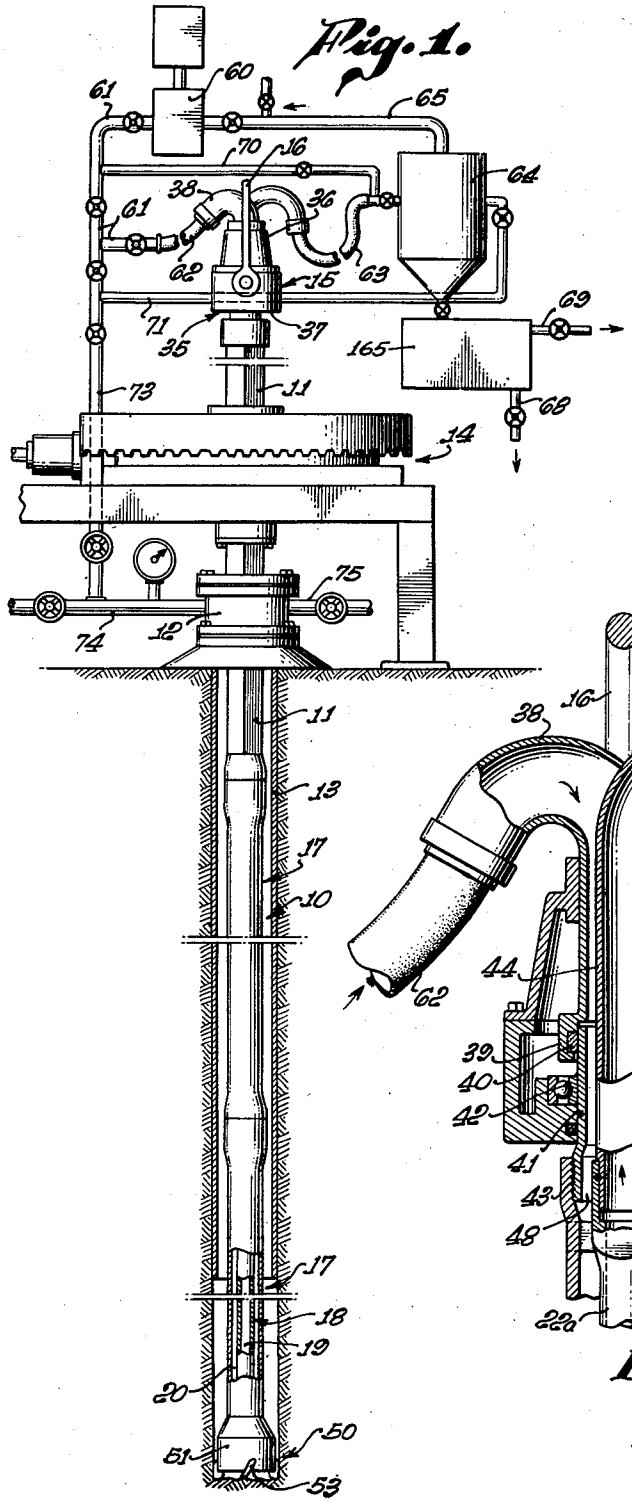


Fig. 3.

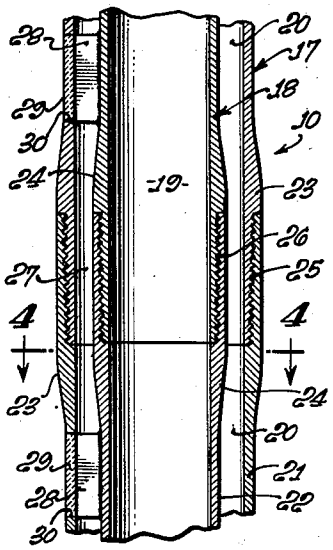
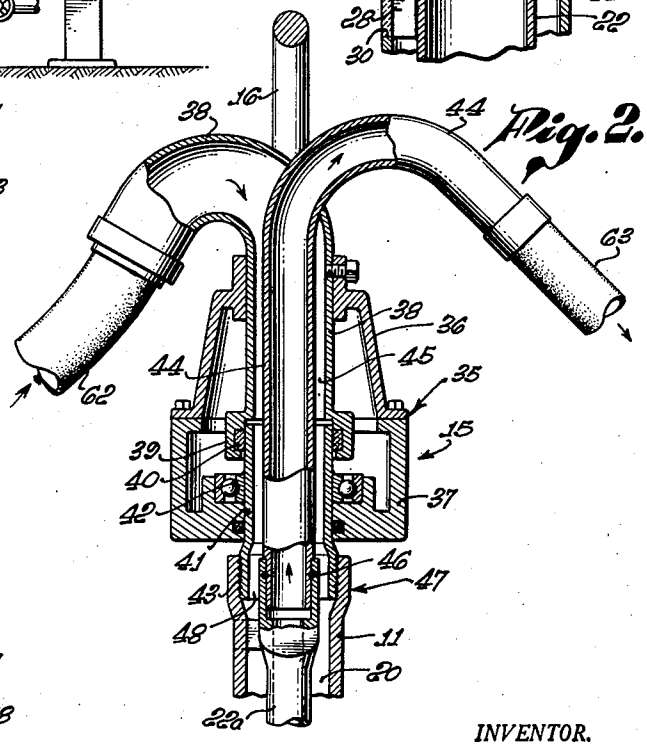


Fig. 2.



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Fig. 5.

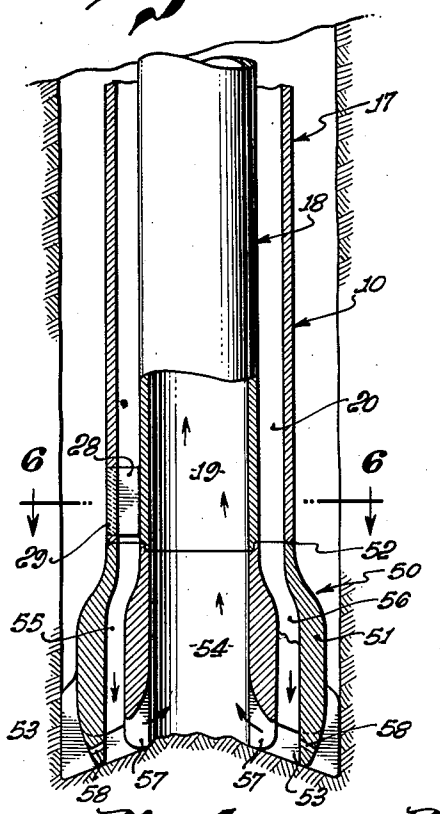


Fig. 7.

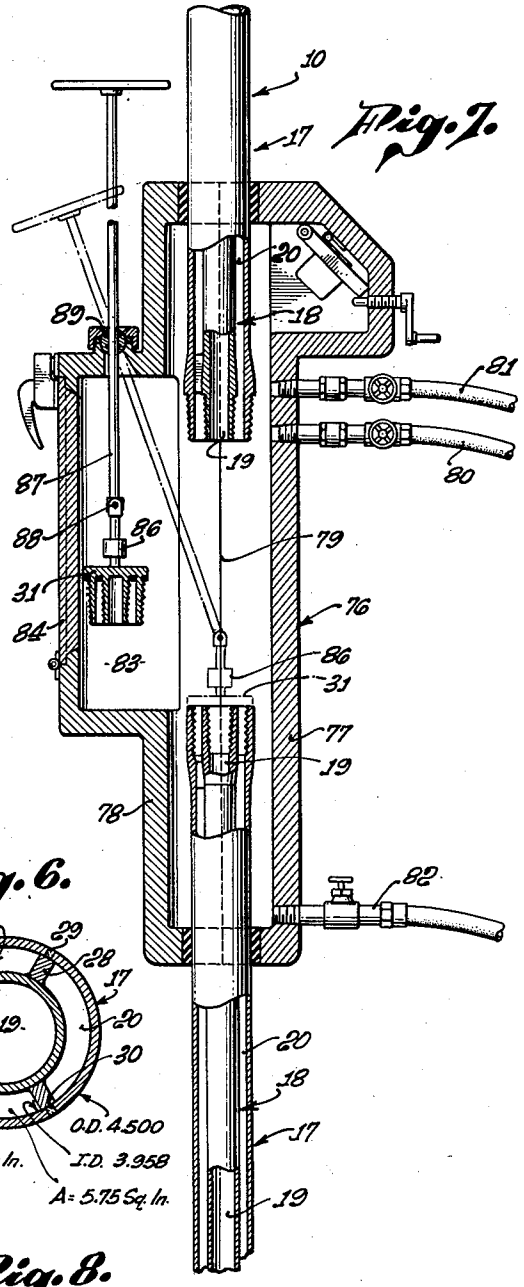


Fig. 4.

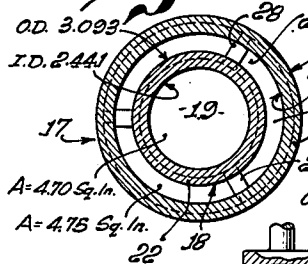
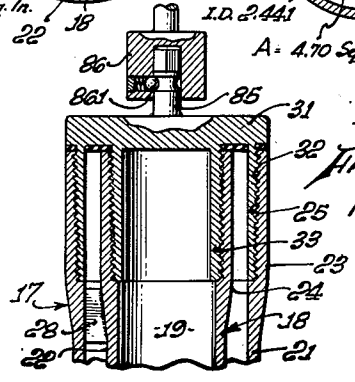


Fig. 6.

Fig. 8.



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METHOD AND APPARATUS EMPLOYING COMPRESSED GAS FOR DRILLING WELLS

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Application August 25, 1951, Serial No. 243,626

7 Claims. (Cl. 255—1.8)

This invention has to do with improved methods and equipment for the drilling of wells employing compressed gas as the fluid medium for carrying bit cuttings and other formation granules to the ground surface.

An appreciation of the objects and accomplishments of the invention may be given to best advantage following a preliminary consideration of certain limitations of conventional drilling practices, and particularly rotary drilling employing liquid circulating fluid. The customary practice is of course to drill the formation using a drill pipe string carrying the cutting tool and through which liquid or mud circulation is maintained down through the bit and upwardly around the outside of the drill string to the ground surface. One fundamental and general fault of the conventional rotary drilling practices is that due to the distribution throughout the well bore of bit cuttings, fluids entering or introduced to the well, the circulation methods employed, and the action of the drill string on the wall of the well in the presence of contaminants foreign to the materials naturally existing at any particular location in the formation, it is impossible to drill a "clean" hole, or ultimately to maintain the formation at the well bore in a natural condition conducive to greatest productivity.

One principal reason for the limitations characteristic of conventional rotary drilling is that with mud being continuously circulated up through and in contact with the wall of the hole, the mud tends to deposit on the bore wall and to become worked into the formation by the action of the drill string as it rubs against the bore wall, thus restricting and frequently virtually closing off the formation against production in-flow. On the other hand the sustained circulation may tend to wash out and cavitate the bore wall to the extent of releasing excessive sand into the well, and creating large voids which give rise to difficulties for such purposes as cementing or water shut-off, gravel packing and other operations. In this connection it is to be noted that the required fluid circulation may necessarily disturb the normal lay of the formation adjacent the well bore so that any loosened sands cannot assume and remain at a normal condition or angle of repose. Another serious limitation is the difficulty, if not impossibility of obtaining accurate information, and particularly true formation samples, showing the composition and condition of the formation encountered at any stage in the course of drilling.

While additional shortcomings of conventional rotary drilling practices might be discussed at length, those referred to in the foregoing will suffice to indicate the desirability for improved drilling methods that offer the advantages made possible by the present invention.

My general object is to provide improved well drilling methods and equipment presenting the general advantage of eliminating the necessity for having to use liquid circulating fluids, and permitting maintenance of a gaseous fluid circulation isolated from direct contact with the well bore wall and fluids, all to the end that drilling may progress efficiently, and the cuttings and sand removed from the well, with minimum disturbance of the natural condition of the bore and adjacent formation. Briefly, the invention contemplates the use of a dual drill string comprising inner and outer annularly spaced pipe strings forming passages through one of which compressed gas is discharged downwardly to a location at the cutting tool where the gas stream entrains a mixture of liquid and cuttings, the gas then flowing to the top of the well through the second passage at a velocity sufficiently high

to assure continued entrainment of all sand and cuttings to be removed from the well. Liquid, such as an oil column, is maintained in the well outside the drill string. While such liquid is available for lubrication of the cutting tool and admixture with the cuttings to be entrained in the gas stream, the well bore outside the drill string is essentially isolated from the gaseous circulating fluid. Thus there exists no opportunity for mud contamination and clogging of the formation at the bore wall, no consequential migration of the cuttings occurs, the uncontaminated cuttings produced at the ground surface at any time truly represent the formation then being drilled, and the well and adjacent formation are left in natural condition with minimum cavitations or caveins most conducive to greatest stability and productivity, as well as best condition for performing such additional operations or treatment, such as cementing that may be required.

The invention has necessitated solving various difficult problems in order that a gas drilling system as outlined, may be practically feasible. One of the major problems encountered, and particularly with respect to the drilling of deeper wells, is that of assuring the maintenance of sufficiently high gas velocities to entrain all the materials to be removed from the well, and to assure continuance of the gas flow at a velocity sufficiently high to keep the materials entrained throughout the course of the gas flow to the top of the well. Also encountered has been the problem of keeping the required gas volume within limits avoiding the necessity for impracticably excessive compressor capacities. Further problems are presented by the necessity for having a double pipe drill string, the joints of which have sufficient internal openness to permit maintenance of the required gas velocities while at the same time having sufficiently great strength to carry the heavy pipe loads encountered in deep well drilling. And in this same connection, it is important that the drilling equipment, particularly the dual pipe string, be capable of handling and be accommodated by available apparatus such as tongs, packers, casing heads and the like.

In accordance with the invention, provision is made for maintaining within the drill string down and up flow gas passages of such openness and linear form as will minimize pressure losses and assure that at practically obtainable input pressures, the gas will have an up flow through the stream at a velocity, say in the neighborhood of 1500 feet per minute, at or above the entrainment velocity of the cuttings or other granules to be removed from the well. As will be understood, by "entrainment velocity" is meant the gas velocity at which the sand or other granules will remain suspended in and carried by the gas throughout the course of its upward flow through the drill string. As will appear and without necessitating detailed discussion at this time, by making up the drill string with externally upset threaded joints it is made possible to obtain the necessary joint strength while maintaining maximum openness or cross sectional areas of the gas passages within the string. Specifically contemplated are dimensional relationships between the inner and outer strings whereby the minimum cross sectional areas of the gas passage within the inner pipe and the annular passage between the pipes, is substantially the same.

The invention further contemplates a closed gas circulating system involving at the ground surface one or more compressors discharging into one of the drill string passages, and appropriate separating equipment receiving the gas and entrained cuttings from the string and discharging the gas, after removal of its entrained materials, to the compressor. Considering the confinement and low volume of the gas required in the drill string, by using at the ground surface a closed return system, circulation of the gas may be conducted at such high pressures and low volumes as to minimize the size of the necessary compressor equipment.

The invention has various additional features and objects, all of which together with those referred to in the foregoing, will be understood to best advantage by proceeding with a description of certain illustrative methods and apparatus embodying the invention, as represented by the accompanying drawings, in which:

Fig. 1 is a general view illustrating the well drilling system, including showings of the drill string and surface equipment;

Fig. 2 is an enlarged cross sectional view of the dual gooseneck swivel head;

Fig. 3 is an enlarged fragmentary section taken longitudinally through one of the pipe joints;

Fig. 4 is a cross section on line 4—4 of Fig. 3;

Fig. 5 is an enlarged scale illustration of a typical cutting tool or bit carried by the lower end of the drill string;

Fig. 6 is a cross section on line 6—6 of Fig. 5;

Fig. 7 is a sectional illustration of a pressure seal mud box useable as hereinafter explained in making up or disconnecting the drill string; and

Fig. 8 is an enlarged view showing a joint section closed by the plug used in the apparatus of Fig. 7.

Referring first to the general showing of Fig. 1, the equipment comprises a hereinafter described dual drill string generally indicated at **10**, which includes the drive stem or kelly **11** extending through an appropriate head **12** on the casing **13**, the casing head preferably being of any of various known types capable of maintaining a fluid-tight seal with and about the kelly **11** during drilling. The drill string is rotated by the conventionally illustrated rotary table **14** through which the kelly extends upwardly to the swivel **15** carrying a bail **16** by which the drill string is vertically supported as by the conventional equipment.

The drill string **10** comprises an outer pipe string **17** and an inner concentric string **18** containing a fluid passage **19**, and spaced from the outer string to provide an annular outer fluid passage **20**. The pipe strings **17** and **18** are made up respectively of pipe stands **21** and **22** of corresponding length, the stands being terminally and externally upset at **23** and **24** with flush or substantially straight line walls at the insides of the upsets. As illustrated in Fig. 3, the stands are terminally threaded to form screwed joints at **25** and **26** within the upsets, the thread series in each joint having a small taper toward the ends of the pin sections of the joints. As will appear, the structural and shape characteristics of this form of joint is of important significance to the adaptability of the composite string to drilling using a gaseous circulating medium, by reason of both the strength and passage areas within the joint. By reason of the external pipe upsets it is possible to provide sufficient metal for the threaded joints at **25** and **26**, and yet maintain sufficient joint strength to carry the drill string load. And by forming the joints with internal flush or substantially straight line walls, it becomes possible to maintain in the annular space at **27** between the threaded ends of the pipes, an area sufficiently large to avoid excessive pressure drops in the compressed gas flow at the joints, and thus assure ultimate maintenance of upward gas flow in the passage **19** at velocities sufficiently high to entrain the cuttings.

The pipe sections **21** and **22** making up the individual stands may be suitably interconnected beyond the joint ends by suitable means which in effect integrates the inner and outer pipes, without however, consequentially restricting the passage **20** between them. As illustrative, the pipes are shown to be interconnected by radial webs **28** welded to the inner pipe **22** and secured to the outer pipe by weld metal **29** (Fig. 6) filled into the slots **30** in the outer pipe which are brought into alinement with the webs initially mounted on the inner pipe. In assembling and integrating the individual stands, the pipes **21** and **22** may be brought into end alinement as shown in Fig. 8, by screwing into the box ends of the pipes a plug **31** having concentric threaded pins **32** and **33**. The plug is screwed fully into the pipes to assure their becoming correspondingly positioned axially and in relation to the plug, following which webs **28** previously welded to the inner pipe, may be welded at **29** to the outer pipe through the alined slots **30**.

The swivel head **15**, given more detailed description in my copending application Serial No. 139,655, now Patent No. 2,657,016 issued October 27, 1953, may be described briefly as comprising a tubular body **35** having upper and lower sections **36** and **37**, within which is carried a non-rotating gooseneck **38**. The enlarged lower end **39** of the latter receives and has a fluid-tight seal as by gasket **40** about a rotating pipe **41** vertically supported on the thrust bearing assembly **42** and having a threaded connection at **43** with the upper end of the kelly **11**. A

second gooseneck **44** positioned concentrically within the outer gooseneck **38** and annularly spaced therefrom to form a passage **45** communicating with the drill string passage **20**, is received within the upper end of pipe **22***a* within the kelly, fluid leakage between the pipe and shank of the concentric being prevented by seal ring **46**. As illustrated, the joint structure at **47** between the kelly and swivel assembly, is such as to provide within the joint a fluid passage **48** having a cross sectional area at least as large as the area of the passage **27** within the pipe string joints. Likewise the diameter of the gooseneck **38** and **44** will be such that the fluid passages **45** and **49** will have cross sectional areas as large as the drill string passages **27** and **19**.

The dual pipe string **10** carries on its lower end a cutting tool or bit generally indicated at **50**, which may be of any of the general types of cutting tools customarily employed, modified and adapted however, to accommodation of the gas circulation in a manner such that the bit cuttings will be entrained in the up flowing gas stream. Typically the bit **50** is shown to comprise a body **51** welded at **52** to the lower end of the pipe string and carrying a plurality of bottom cutters **53** extending radially outwardly from a central passage or bore **54**. The bit contains a substantially annular fluid passage **55** interrupted only by vertical webs **56** integrating the inner and outer portions of the bit body, passage **55** being so proportioned that its cross sectional area is at least as great as the cross sectional area of the communicating drill string passage **20**. Passage **55** communicates at its lower end with openings **57** shaped as illustrated to direct the compressed gas stream discharged downwardly through passage **20** reversely and upwardly within bore **19** of the inner string. As in the case of passage **55**, the total cross sectional area of openings **57** traversed by the gas stream, will be at least as great as the area of the pipe string passage **20**. The bit may contain additional openings **58** through which liquid from a hydrostatic column standing in the well outside the drill string, may flow restrictedly into the bit at its cutting face.

Referring again to Fig. 1 compressed gas is discharged from the conventionally illustrated compressor **60** through line **61** and hose **62** into gooseneck **38** to be circulated down through the drill string passage **20**, the bit **50** and up the inner string passage **19** to gooseneck **44**. The gas then flows through hose **63** to suitable equipment typified by the cyclone separator **64** and closed settling chamber **165** for removing liquid and solid entrainment from the gas stream being recirculated to the compressor through line **65**. As will be understood, the compressor discharge and return lines (through the separator) constitute a closed system permitting operation of the compressor on gas retaining substantial superatmospheric pressure following its circulation through the drill string.

In considering the operation of this system, assume the equipment to be set up as illustrated in Fig. 1, with the compressor **60** operating to discharge through line **61** into gooseneck **38**, compressed air or a compressed hydrocarbon gas typically methane. The gas flows downwardly through passages **45**, **48** and **20** and the bit passage **56** into bore **54** and the inner drill string passage **19**. With the bit being rotated to drill the formation, the cutters **53** progressively disintegrate and penetrate the formation while being lubricated by liquid from the hydrostatic column standing say at a level LL in the well, so that there occurs a constant though restricted and relatively small volume flow of the well liquid into the bit. As a result, there is formed within the bit and at the location of the openings **57** a slurry of the well liquid and bit cuttings. By reason of the high velocity gas flow at its point of reversal within the openings **57** (as permitted by the open condition of the circulating passages within and throughout the drill string) the slurry is entrained in the gas stream and carried thereby up through passage **19** and gooseneck **44** into the separator **64**. Even in the drilling of deep wells, it is possible to maintain within passage **19** a gas velocity, say in the neighborhood of 1500 feet or above per minute, sufficient to assure continued entrainment of the cuttings throughout the course of the gas flow to the ground surface. From separator **64** the liquid and cuttings may be taken to a closed settling tank **165** from which the cuttings are removed through line **68** and the liquid drawn off separately through line **69**. If for any reason it should be desirable to reverse the gas circulation through the drill string, the compressor discharge may

be directed through lines **61** and **70** to the hose **63**, and the gas stream and entrainment being discharged from the string through hose **62**, may be conducted by way of line **71** to the separator **64**.

From the foregoing it will be understood that during the drilling operation, the gaseous fluid circulation is confined essentially to the dual passages within the drill string, and that as a result no circulation flow occurs within the well outside the drill string and in contact with the well bore wall. As a consequence, the well remains in a relatively uncontaminated condition with the formation at the bore wall in a natural state, free from foreign materials and clogging accumulations which ordinarily result from conventional mud circulation. It follows therefore that the cuttings being produced at the ground surface correctly represent the true form and composition of the structure being drilled at the time.

It is also contemplated that provision may be made for controlling the effective well pressure outside the drill string and existing at the bit, as for example to assure confinement of the circulating gas to the drill string passage, and as a further control of the rate of well liquid inflow to the bit. For this purpose compressed gas may be discharged from line **61** through lines **73** and **74** into the well so that the pressure may be maintained therein at any desired value. When no liquid is being produced in the well, a suitable bit lubricating liquid such as oil, may be introduced to the well intermittently or continuously, as through line **75** connecting with the casing head.

Since for the purposes of the described operations the well is maintained under pressure provision may be made for running the drill string into and out of the well without loss of its pressure. For this purpose I may employ a pressure seal mud box and plug applicator of the type shown in Figs. 7 and 8 and as more particularly dealt with in Patent No. 2,522,444, issued September 12, 1950, to me on Well Fluid Control. Briefly, the apparatus shown in Fig. 7 comprises a housing generally indicated at **76**, comprising a pair of sections **77** and **78** adapted to be applied about successive pipe stands at their joint. As shown in the patent, the housing sections may be hinged together to be swung about the pipe string to the point of inter-engagement at **79**. Section **77** is connected to liquid and air lines **80** and **81**, and has a drain line connection **82**. Section **78** has an offset recess **83**, accessible through a sealed and latched door **84**, which contains a plug **31** of the type previously described with reference to Fig. 8, adapted to be screwed into the upper end of a lower stand after disconnection from the pipe stand above. Plug **31** is shown to carry a flatted wrench stud **85** engageable by a wrench socket **86** carried on the end of a rod **87** below its universal joint **88**. The socket is releasably engaged with the stud by means of the spring pressed detent **861**. Rod **87** extends through a swivel ball **89** mounted for rotation to accommodate the rod movement and having sealed engagement with the rod.

In coming out of a hole, the housing **76** is clamped about the pipe joint at the lower end of a withdrawn stand, the latter is unscrewed and elevated to the Fig. 7 position, and by manipulation of rod **87** and plug **31** to the broken line position, the plug is screwed into the lower pipe stand to close and seal it against fluid escape. The housing is then removed, the disconnected stand set to one side, and the drill string is then elevated to bring the next lower joint above the rotary table so that the described operation may be repeated after installation of another plug **31** within the housing.

In lowering the drill string into the well, a reverse procedure is followed. Assuming the lowermost stand remaining in the well to be plugged at its lower end, the housing **76** is placed and sealed about both the lower stand and an upper stand suspended in the Fig. 7 position and closed at its upper end by one of the plugs. The plug in the drill string is removed by way of rod **87** and its wrench tool **86** and the plug is swung to one side within the recess **83**. Thereupon, the upper pipe stand may be lowered and screwed into the box end of the joint section below. The housing **76** is then removed from the pipe, the drill string, with its upper end plugged, is lowered to permit application of the housing about the upper end of the string and the housing about the upper end of the string and the pipe stand to be added, and the described operation is repeated.

Reference previously has been had to the importance of the drill string make-up and construction, and particularly the material and passage area requirements in order that the string may have the necessary strength and unrestricted gas-passing capacity. Figs. 4 and 6 illustrate the dimensions given the pipe walls and gas passages, respectively in the transverse planes of the upset end of the stand and the reduced and uniform diameter extent between the upsets. The upset portion of the outer pipe **21** has an outside diameter of 4.750 inches and an inside diameter of 3.958 inches. The upset end of the inner pipe **22** has an outside diameter of 3.093 inches and an inside diameter of 2.441 inches. The gas passages **19** and **20** have closely corresponding cross sectional areas respectively of 4.70 and 4.75 square inches. Beyond the upset, the outer pipe has an outside diameter of 4.500 inches and an internal diameter of 3.958 inches; the inner pipe having an outside diameter of 2.875 inches and an inside diameter of 2.441 inches. The cross sectional area of passage **19** remains the same at 4.70 square inches, with the passage **20** between the pipes enlarging to 5.75 square inches. While it is desirable that these dimensions, or their relative values be maintained, since they permit the making of a drill string which may be run in practically all casing and well bore sizes encountered, it will be understood that minor variations may occur so long as the essential strength and openness of the gas circulating passages are retained.

I claim:

1. Well drilling apparatus comprising: a drill string comprising a pair of inner and outer concentric spaced pipes connected together for movement as a unit and providing a central string passage surrounded by an annular string passage, said passages being substantially unrestricted throughout their lengths and of about the same minimum cross-sectional areas; a bit secured to the lower end of said string and comprising a pair of inner and outer spaced concentric tubular parts secured together for movement as a unit and providing substantially unrestricted central and annular passages extending through said bit in registration with and corresponding in cross-sectional areas to said string passages; cutting means extending across said bit parts at their lower ends with the lower cutting edges of said means being substantially flush with the lower ends of both of said outer and inner bit parts, said inner bit part having openings in the lower end thereof extending upwardly from said lower edges of said cutting means, the total cross-sectional area of said openings being substantially the same as the cross-sectional area of each of said passages, whereby gas can be flowed at high velocity downwardly through said annular string and bit passages, through said openings at the lower end of said inner bit part, and upwardly through said central bit and string passages for entraining cuttings as they are formed by said cutting means and carrying such cuttings to the surface of a well, and the annular lower end of said outer bit part will engage with the formation at the bottom of a bore formed by said bit.

2. The structure defined in claim 1 in which the lower end of the inner bit part is offset rearwardly of the forward end of the outer bit part.

3. The structure defined in claim 1 in which the cutting blades extend outwardly beyond the periphery of the lower end of the outer cutting bit part.

4. The structure defined in claim 1 including means for maintaining the high velocity flow of gas.

5. The structure defined in claim 1 including means defining restricted openings in the outer bit part adjacent the lower end thereof, the total cross-sectional area of said openings being less than the cross-sectional area of each of the passages.

6. The method of drilling a bore in formation, the steps comprising: advancing a cutting tool into the formation to form granular cuttings at the bottom of the bore; conducting a high-velocity continuous stream of gas substantially unrestrictedly downwardly through the bore in isolation from the side walls thereof to the bottom wall thereof; continuously passing said gas stream unrestrictedly between a major portion of the lower face of said tool and the bottom wall of the bore to entrain the cuttings in said stream as they are formed; continuously conducting said stream with the entrained cuttings substantially unrestrictedly upwardly through the bore in isolation from the side walls thereof and from said down-

flowing portion of said stream to the surface of the formation; and confining said gas stream to exposure only to the bottom wall of the bore in passing between the bottom wall and said tool by maintaining an auxiliary pressure in the bore between the side walls thereof and the tool which is isolated from said downflowing and upflowing stream portions and which is slightly greater than that of said stream at the bottom wall of the bore.

7. The method defined in claim 6 in which the pressure in the bore between the side walls thereof and the tool is created by maintaining a liquid column in the bore.

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