AIR, GAS, AND FOAM DRILLING TECHNIQUES

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INTRODUCTION

The use of air or gas as a circulating medium was introduced in the early 1950's. Even though initial attempts were crude, significant increases in penetration rate and bit life were obtained. Since these initial attempts, development of air and gas drilling techniques has expanded; they are widely accepted today as a method to reduce drilling times and cut cost of many wells. Along with the time and resultant dollar savings, other advantages such as immediate and continuous hydrocarbon detection, minimum damage to liquid-sensitive pay zones, better control of lost circulation, and cleaner cores are obtained.

Today's air drilling technology is attributed to many drilling people whose initiative and accumulative experience have refined the method and determined situations where the technique is most applicable. The lack of understanding, rather than inexperience, is often the reason for not accepting air drilling. Drilling with air does involve special consideration in the use of equipment and drilling techniques that are not commonly encountered with other drilling media. For example, air, unlike fluids, compresses readily and requires a more sophisticated engineering approach to achieve the desired results.

This paper discusses the mechanics of air drilling, modifications such as mist or foam drilling, unique equipment requirements, and downhole problems that have been encountered. Special attention is given to describing techniques developed to prevent or control downhole problems.

DISCUSSION

Mechanics of Air Drilling

Air is the ultimate low density drilling medium. Optimum results and greatest economy from air drilling depend on several factors. Hard formations which are dry or produce relatively few formation liquids provide the best results while air drilling. When the formation is completely dry, or the influx of liquids is slight enough to be absorbed in the air stream, the drill cuttings return to the surface in the form of dust. Also, this allows for immediate and continuous evaluation of hydrocarbons.

Other proven advantages for the use of air are: (1) low cost, (2) increased penetration rate, (3) longer bit life, (4) better control in cavernous and lost circulation areas, and (5) minimum damage to liquid-sensitive pay zones.

The fact that the drill string will always be on bottom when gas is encountered is a big advantage in well control. If the hole is gas free when a trip is made, it will be gas free when the new bit is returned to bottom. Mud-filled holes sometimes allow gas to unknowingly enter the wellbore on trips, due to reduced hydrostatic pressure, and create well control problems. Gas which has already penetrated during air drilling operations will enter the wellbore on trips; however, this gas is always a known quantity and can easily be jetted away from the rig and operating personnel by using jets on the blooie line. This jetting procedure and operation will be discussed later.

The biggest enemy air drilling has is large water-bearing formations. The rate of formation water influx which can be handled is not defined. When water is encountered, mist (foam), aerated, or slug drilling can be used. Mist drilling can handle up to about 200 barrels-per-hour water influx. When surface pressures exceed the limit of the air compressor equipment, aerated or slug drilling can accommodate larger volumes of water.

Other disadvantages to air drilling are: (1) the possibility of downhole fires and explosions, (2) sloughing of formations (when dry or wet), and (3) soft formations. These disadvantages reduce the efficiency of air drilling; however, with air equipment available today, they can be handled.

Increased penetration rate is among the first benefits noticed when air is used as a circulating medium. This increased penetration rate is due to the low density of air or gas which minimizes hydrostatic pressure and aids fracturing at all times. The effect of fluid column pressure on penetration is illustrated in Figure 1.[1] Differential pressure in this example is the difference between fluid column pressure and pore fluid pressure when drilling mud is used.

Actual rock removal or cutting is done by subjecting the rock to compressive loads greater than its ultimate strength. As the bit rotates, the rock is caused to fail or fracture under this dynamic loading. Crushed formation or chips literally explode off bottom and are swept into the air stream and are carried to the surface. This explosion or rapid manner in which chips are removed from bottom is a result of maximum differential pressure into the wellbore.

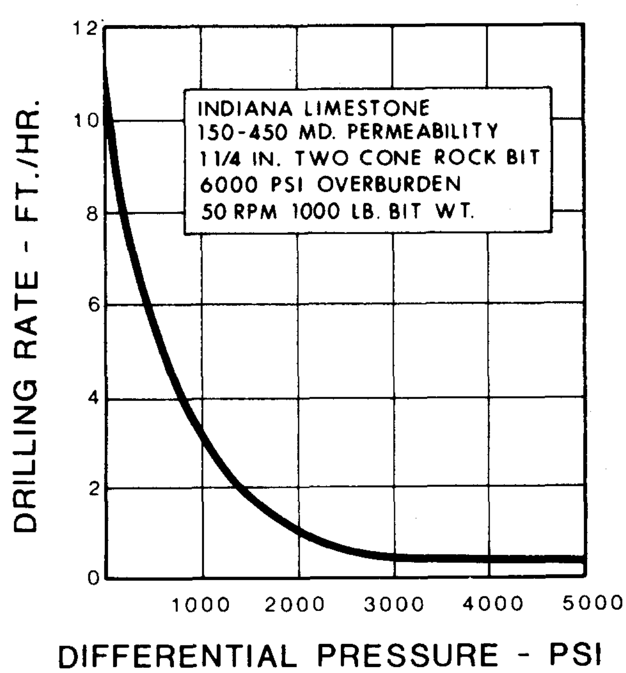


FIG. 1—EFFECT OF DIFFERENTIAL PRESSURE ON DRILL RATE (CUNNINGHAM AND EENINK)[1]

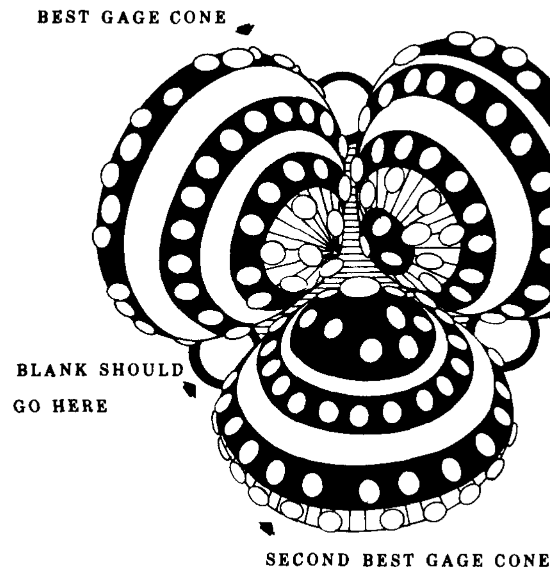


FIG. 2—BLANKING ONE JET NOZZLE

Chips which are removed from the bottom range in size from fine to coarse. As these particles start up the annulus, the larger sizes are ground and pulverized by the drill string. Also, the high velocity forces the cuttings to collide with each other, the tool joints, and the wall of the hole. These actions reduce the sizes of the drill cuttings to the small dustlike particles seen at the surface.

Routing drill-off tests can be run to obtain the optimum penetration rate. It is suggested, because of the faster penetration rates with air, that a drill-off test be conducted over at least 60 feet. That is, the same weight on the bit and rotary speed is applied over 60 feet, and the penetration rate is averaged. Then, either the weight on the bit or the rotary speed is changed, and the process is repeated. This procedure averages out thin formation changes and provides the optimum penetration rate.

Bit performance is an important factor in any drilling operation. In air drilling, the bit with the best gauge protection should be selected. This, in some cases, necessitates counting and comparing the outer row of inserts or teeth. The bit with the most outer row inserts, or teeth, gives the best performance by holding its gauge longer.

One of the detriments in air drilling is bits going out of gauge. This problem is most prevalent when hard, abrasive quartzite sands are drilled.

Reaming behind an out-of-gauge bit causes

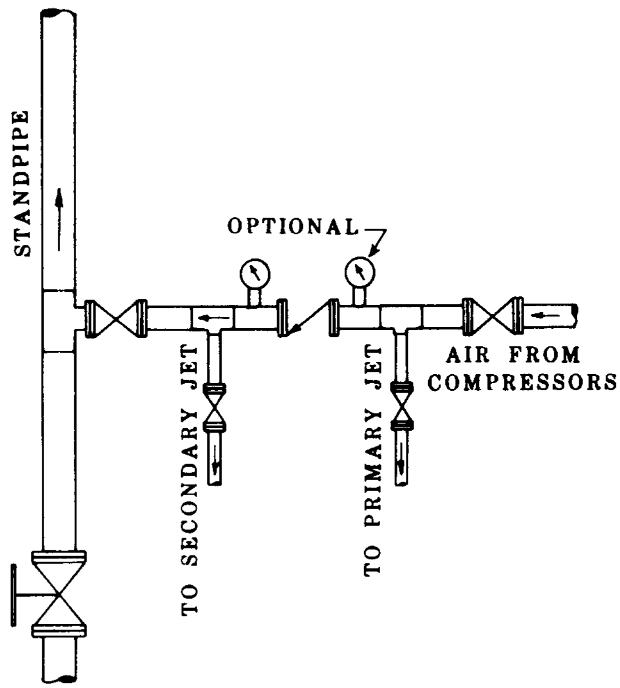


FIG. 3—VALVE MANIFOLD ON STANDPIPE FOR AIR DRILLING

premature bearing failure of the bit being used to ream. This is caused by a pinched bit when the bit reaches bottom after reaming. Premature bearing failure shortens bit life and necessitates the use of more bits per well.

Hard-formation insert-type bits are used in most air drilling operations. Today's market offers bits made for air drilling. Some of these bits, however, are manufactured for mining operations. These mining bits have outside diameters which range from zero to 1/4 inch; i.e., a 7-7/8 inch bit could be no smaller than 7-7/8 inch but could be as large a 8-1/8 inch. Also, some bits are manufactured for oilfield air drilling. These bits have outside diameter specifications which are the same as bits normally used to drill with mud.

When an air bit is used, experience has shown that bit life and penetration rate can be improved by blanking one jet nozzle. When a blank is used in a jet nozzle, the blank should go between the cones with the most gauge inserts (see Figure 2). The reason for this is that the cones on each side of the blank will bear most of the cutting load while drilling. Therefore, these cones should have the most inserts and best gauge protection. Under normal conditions, the other two open jets should be left open or jetted with 20/32-inch or 24/32-inch jets.

The blank jet, in an air bit, improves bit life because the blank restricts air flow through the jet nozzles. This increases the back pressure at the bit and forces more air through the air tubes and across the bearings. This keeps the bearings cooler and cleaner and will extend bit life. The pressure increase, due to blanking one bit jet, is about 10 to 15 psig.

The second advantage to a blank jet is better hole cleaning, resulting in most cases in faster penetration. The blank jet forces the air to flow across the bit face, thereby removing cuttings from the center of the bit and preventing any regrinding of cuttings which would be trapped under the bit. Symmetrical jetting can, under certain conditions, build up cuttings in the bit center. Effects vary with various formations; however, possible advantages have to be weighed against negatives, such as reduced bit-bearing cooling.

Equipment Required for Air Drilling

Conversion of a conventional rotary rig to an air drilling operation is a simple matter. Most of the liquid and solids handling equipment, normally used for mud drilling, can be removed. For an air drilling operation, the liquid handling equipment should consist of one mud pump, a centrifugal transfer pump and about 1,500 barrels of water storage (steel mud pits can be used for water storage).

A valve manifold is welded to the standpipe on the rig floor (see Figure 3). The hardware, valves, and lines in this manifold should be sized and pressure-rated to provide minimum friction losses and maximum operating pressures.

A rotating drilling head (rotating blowout preventer) is essential (see Figure 4). The rotating head maintains a constant seal around all rotating elements in the drill string except large diameter pieces, such as large drill collars, reamers, and drill bits. The rubber seal unit seals around any shape (kelly or drill pipe). This packing element rotates with the drill string. This allows the drill cutting or dust to be directed out the flanged outlet and away from the rig via the blooie line.

Proper alignment of the rotating head is essential. This will save time on connections and prevent undue wear on the rubber element and bearing

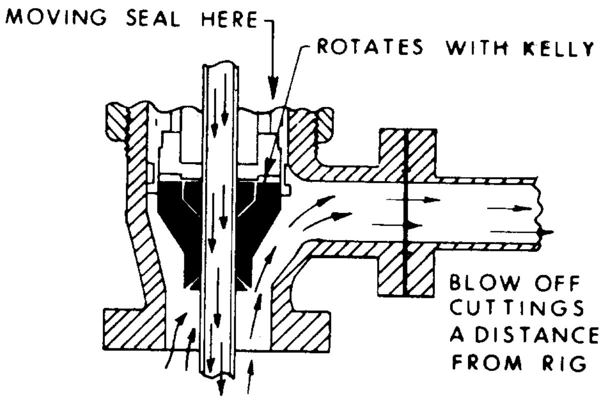


FIG. 4—AIR OR GAS DRILLING DIAGRAM THROUGH THE ROTATING HEAD

structure. A method for proper alignment of the rotating head is to set a drill collar on the slips in the rotary table and center the drill collar in the rotating head. Centering can be done by using a steel tape line and measuring from the inside diameter of the rotating head to the outside diameter of the drill collar. Corrections in alignment can be made with chains and boomers. When the rotating head is properly aligned and centered, braces can be attached to the head and to the substructure. Welding these braces will prevent movement and misalignment during drilling operations.

The life of the rubber element in the rotating head can be extended by keeping the kelly well lubricated while drilling. This is easily done by pouring water, or liquid soap, or both on top of the rubber element after each connection. Oil can be used for kelly lubrication; however, oil tends to pack cuttings, which can restrict air flow, in the rotating head.

Other blow-out control equipment is no different from that normally used for mud drilling. A double ram BOP stack sized to meet anticipated pressure requirements is sufficient.

For today's air drilling operations, air compressors are available which provide adequate air volumes along with portability. The most commonly used oilfield air compressor is a positive displacement, double acting, reciprocating, two- or three-stage type compressor. This type compressor offers a wide range of sizes and pressure ratings necessary for an efficient drilling operation. Also, this type compressor has been designed for continuous operation.

Package units consisting of two or more compressors can be put together. The number of compressors in a package will depend on the air volume required to drill the hole efficiently. Generally, one air compressor, available on today's market, for oilfield drilling will put out from 400 to 1200 cubic feet of air per minute at 300 to 320 psig maximum pressure.

The positive-displacement type air compressor is rated according to piston size, and the output is dependent upon the altitude at which the compressor operates. Compressor manufacturers can provide data on volume output at varying operating pressures. However, a sure way to know what air volume is being pumped is to actually measure the air output at drilling pressures. This is easily done by holding back pressure on the compressor (100 to 200 psig) and measuring the output volume with a flow meter or orifice well tester. This is the only way to be sure of the actual volume being delivered to the bit.

Another type compressor which is making its entry into air drilling is the high pressure helical screw, two-stage compressor. This type compressor is a positive displacement, oilflood lubricated, type compressor which provides a constant volume at variable pressures. The screw-type compressor is rated at 750 to 800 cubic feet per minute at 300 psig.

A booster is required if drilling pressures exceed the pressure capabilities of the compressors. The booster should be sized to handle all the compressor volume being used. The oilfield booster will increase pressure from about 300 psig to about 1500 psig. The booster is necessary insurance on an air drilling operation should hole trouble develop. The various instances in which a booster is necessary are discussed under "Air Requirements."

Other equipment necessary in an air package for an air drilling operation is a mist or foam unit. This unit consists of a 40 to 50 horsepower triplex plunger pump capable of delivering 25 to 35 GPM. The triplex pump takes suction from a 12-barrel tank which is used to accurately measure water injection rate. Also, an air-operated chemical injection pump capable of an injection rate of about 10 to 15 gallons per hour is required for foaming agent (soap) injection. The chemical pump allows accurate measurement of injected foaming agent.

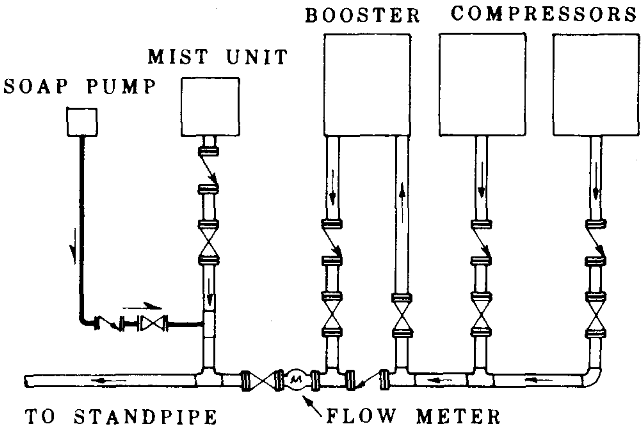


FIG. 5—COMPRESSOR, BOOSTER, AND MIST UNIT

Figure 5 illustrates how the compressors, booster, and mist unit are hooked-up for an air drilling operation.

A 7- to 10-inch ID flow line, the blooie line, carries the drill cuttings, and dust away from the rig. The blooie line is normally 150 to 200 feet in length and should be well anchored, flanged, and welded (see Figure 6). It is very important that the blooie line have no angled connections, such as 45-degree or 90-degree bends. Any angled connection in the blooie line is dangerous because dust will cut-out the line or establish a thin wall condition at the bend. Also, because of the pressure drop around these bends, surge pressures can part the line. These surge pressures occur while unloading liquid from the hole with air or if unexpected formation liquids are encountered and are brought to the surface by the air.

Besides being straight, flanged, and welded, the blooie line has six other major components. These components are: (1) a gas or air jet, (2) a deduster, (3) a drill cutting sample catcher, (4) a hook-up for a gas sniffer, (5) a hook-up for going to fluid drilling, and (6) a pilot light.

The gas or air jets are used to keep gas off of the rig floor and away from rig operating personnel during trips. As illustrated in Figure 7, the jets are of two different designs and serve two functions. The jet at the end of the blooie line is the primary jet and is used on round trips. The secondary jet, located nearer the rig is used only if the primary jet fails to function properly due to being cut-out by dust-cutting action. Also, the secondary jet is used to bleed off the air pressure prior to making connections.

The primary jet should be located four pipe diameters from the end of the blooie line for best results. For example, if a 7-inch blooie line is being used, the jet should go 28 inches (7 inches X 4) from the end of the blooie line. The theory behind the location of this jet is not relevant to this paper. It is known, however, that when properly installed, it is far superior to any other jetting method. Actual field measurements have shown that the primary jet will pull 6 pounds of vacuum on the blooie line. The secondary jet will pull only 2 pounds of vacuum. These measurements were made using the capacity of one air compressor (about 1200 CFM) through a

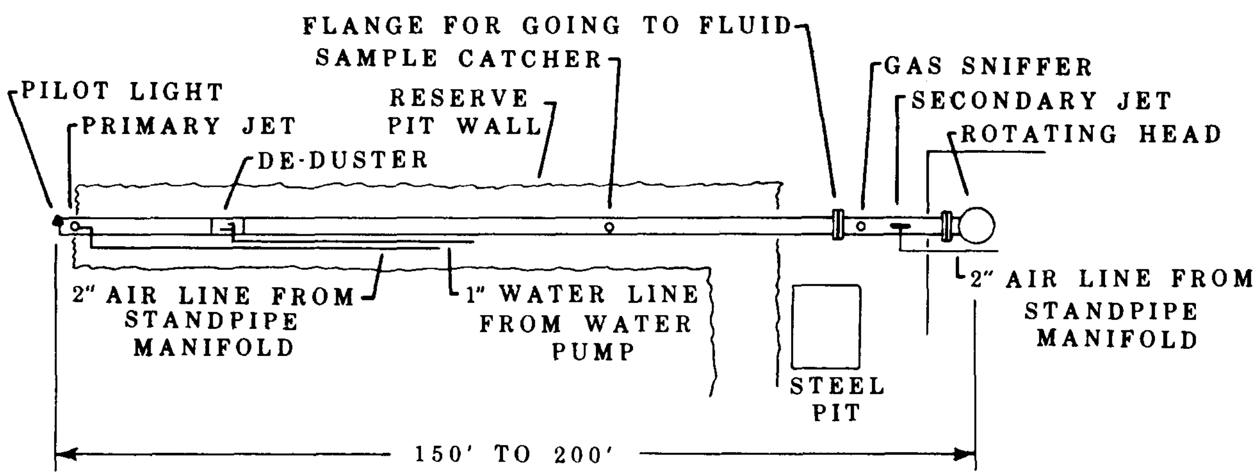


FIG. 6—BLOOIE LINE

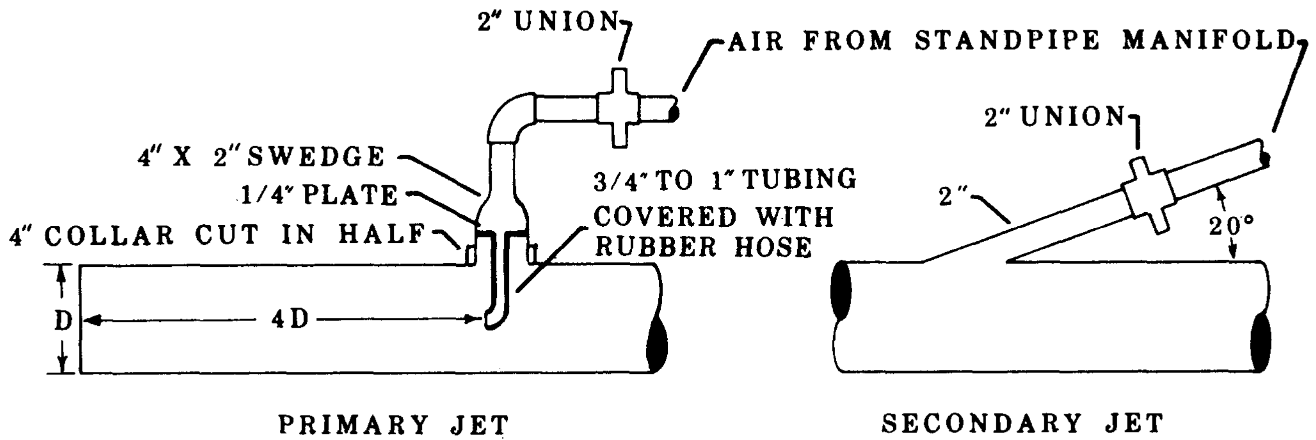


FIG. 7—GAS OR AIR JETS

2-inch line and a vacuum gauge installed between the secondary jet and the rig. Air was passed through each jet at different times, and the amount of vacuum created by each jet was noted.

Although it is not clearly defined, it is believed that the primary jet will safely keep 3 to 5 MMCFD gas production from the rig floor while round trips are being made. This is assuming that the rotating rubber has been pulled. Greater volumes of gas may necessitate stripping in and out of the hole by leaving the rotating rubber in place.

The "de-duster" is used to suppress drill cutting dust while drilling. In remote areas the de-duster is used only when the wind carries the dust in the direction of the rig or other equipment. In populated areas or areas where dust is not desired, continuous operation is necessary.

Water used to suppress the dust can be picked up by a pump from the reserve or burn pit and circulated for re-use.

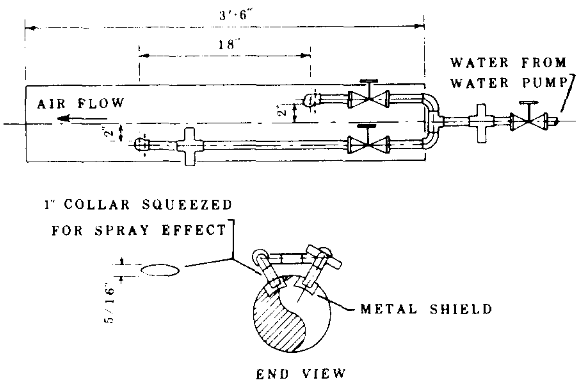


FIG. 8—DE-DUSTER

The de-duster is easily constructed and installed on the blooie line. The de-duster design shown in Figure 8 can suppress dust at a penetration rate of over 100 feet per hour.

A "sample catcher" of the type shown in Figure 9 is installed on the blooie line to catch drill cutting samples. The sample catcher also serves a more important function for drilling people. It allows observation of the dust when the de-duster is being used. This is necessary because, should the dust disappear, a damp or wet downhole condition exists, and trouble is pending or has already occurred. This trouble comes in the form of downhole fires and/or a stuck drill string. The detection and control of these problems are discussed under "Downhole Problems" and "Downhole Fires and Explosions."

A gas sniffer unit, similar to those used in mud drilling, can be hooked into the blooie line to detect very small gas entries or background gas (see Figure 6).

For convenience and ease of handling, a hook-up

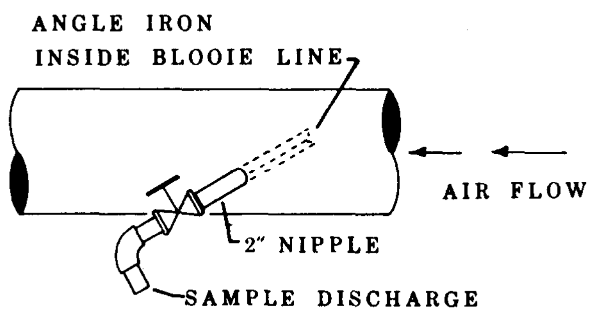


FIG. 9—SAMPLE CATCHER

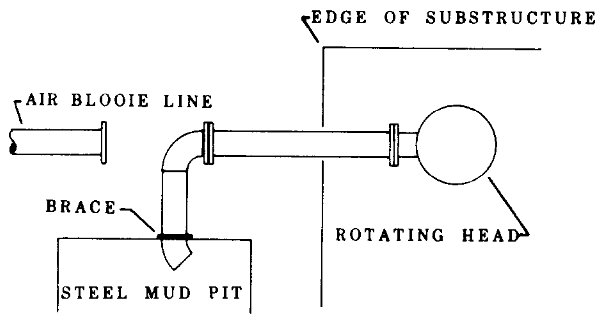


FIG. 10—HOOKUP TO GO FROM AIR TO MUD

similar to that shown in Figure 10 can be used if it becomes necessary to go to mud.

A small flare or "pilot light" should be maintained at the end of the blooie line. This will ignite any gas which is encountered.

One of the most important aspects in air drilling is constant monitoring of drilling pressure. A minimum of two chart-type pressure recorders is required to properly monitor air pressure. One pressure recorder should be on the rig floor, and a second recorder immediately downstream of the air compressors.

The chart-type pressure recorder on the rig floor should be a 0 to 500 psig, 12- or 24-hour pressure recorder. The pressure recorder at the air compressors is a part of an orifice meter run where constant pressure and differential are measured. This will allow easy calculation of air volume output at any point in time, which is very important should the air pressure drop or increase. For example, if an increase in air pressure is not accompanied by a corresponding increase in air-volume output, pending trouble is indicated. This trouble could be that a wet or damp hole condition has been encountered, that gas or other hydrocarbons have been encountered or the hole is not being properly cleaned.

A high-pressure alarm should be installed on the rig floor. This alarm should be set to indicate any 5- to 10-psig increase in drilling pressure. The action which should be taken if a pressure increase or decrease is encountered will be discussed later in this paper.

A spring-loaded, dart-type float placed immediately above the bit prevents the back flow of gas, air, or both while making connections or round trips. A bit sub or bottom-hole drill collar is bored out to hold the bottom hole float. A flapper type float placed in the top of the drill string improves air drilling efficiency. The flapper or "string float" is placed in a sub bored for this float.

The string float shortens connection time by trapping air volume and pressure between it and the bottom hole float. Therefore, less time is required to get this compressible medium back to drilling conditions. The string float, by trapping air below it, keeps air moving around the bit while connections are being made.

It is absolutely necessary to have air circulating around the bit before drilling is started. This prevents dry drilling and prolongs bit life. Because air, unlike mud, is compressible, a period of time is required to establish air circulation around the bit after a connection is made. Circulation around the bit is established if there are returns coming from the blooie line or the air pressure has reached the normal drilling pressure. After a connection, drilling should not begin until one of these two conditions is met.

Short trips can be made to remove the string float for running deviation surveys or to keep the string float as high in the string as possible. Also, more than one string float can be run if a short trip is undesirable. The float should have sufficient inside diameter to allow free point and back-off tools to be run through it, should fishing operations be necessary.

The string, flapper-type float can be held open to bleed off pressure by using a bar on a wire line. Also, a small hole can be bored in the flapper; this hole

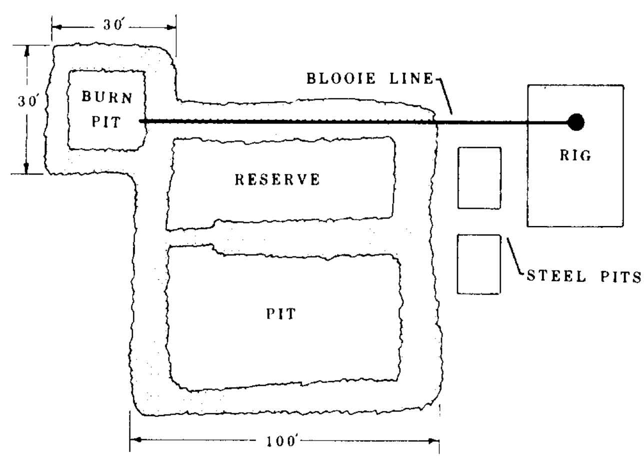


FIG. 11—RESERVE PIT FOR AIR DRILLING (SIZE WILL VARY)

allows pressure to slowly bleed off. The string float will present no problem should fishing operations be necessary. As mentioned above, the advantages of the string float far outweigh the disadvantages.

The reserve pit design for an air drilling operation should provide for a burn pit behind the standard mud drilling reserve pit (see Figure 11). The blooie line should extend past the reserve pit and exhaust into the burn pit. This prevents any hydrocarbon liquids from burning, flowing, or burning and flowing into the reserve pit and prevents a reserve pit fire near the rig.

Air Requirements

The single most important factor to consider in setting up an air drilling operation is the volume of air necessary to do the work. No upper limit has been established for air drilling requirements; i.e., there is no such thing as too much air. On the other hand, the reason air drilling fails is very often insufficient air volume to clean the hole efficiently under a varied range of drilling conditions.

The theory behind the use of air as a circulating medium relating to such things as lifting power and annular velocity will not be discussed. What is important is the air volume necessary to get the job done efficiently and with the least amount of trouble. An air drilling operation is in trouble if there is insufficient volume available to handle wet hole, sloughing shales, and mist or foam drilling conditions.

Experience in air drilling over 3,000,000 feet of hole with an over-all average penetration rate of 1,000 feet per day per rig in hard rock shows that an air volume of 2,000 to 2,400 cubic feet per minute is adequate to keep the hole clean and to drill efficiently over a wide range of drilling conditions. This volume of air (2,000 to 2,400 CFM) is based on 7-7/8-inch hole using 4-1/2-inch drill pipe. Larger hole sizes will require more volume, while small hole sizes will require less air volume. A good rule of thumb to indicate whether enough air is being used is to stop drilling, and measure the time required for the dust to stop or clean-up at the end of the blooie line. The time required to clean the hole should not greatly exceed one minute per 1,000 feet of depth.

Table 1 indicates a good starting point for determining air requirements. It should be kept in mind that experience has shown that most of these air-volume requirements are lower than what is actually needed to drill an efficient, trouble-free hole.

As mentioned earlier, most oil field compressors used for drilling will have a maximum pressure output of from 300 to 320 psig. Additional pressure will have to be achieved by using a booster. A booster increases pressure from 300 to 1500 psig. The additional pressure is necessary for air mist drilling operations and for blowing the drill string loose should a sloughing shale problem be encountered. In some cases, the additional pressure can prevent a stuck drill string.

When formation water production cannot be dried up or when hydrocarbons are encountered, foam or "mist" drilling is necessary. Mist drilling will require about 30 to 40 percent more air than dusting. Standpipe pressures will be greater. Mist drilling pressures will range from 200 to 400 psig as compared to 100 to 300 for dust drilling. The additional air volume and pressure are required because of the weight of the water being lifted. Foaming agents, "soap", and injected water requirements for mist drilling are discussed under "Downhole Problems."

A mist drilling operation can easily become a slug-

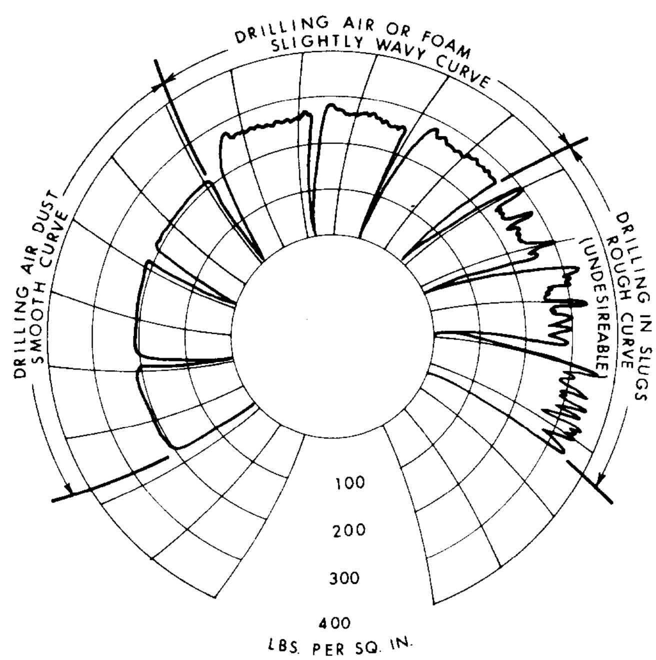


FIG. 12—PRESSURE OF MIST AND SLUG DRILLING

drilling process if drilling pressure is not continuously monitored and soap and water injection volumes are not balanced to meet exact drilling conditions. Figure 12 illustrates the pressure behavior of mist and slug drilling.

Pressure surges in the hole, caused by heading, are detrimental to hole conditions. For this reason, slug drilling, which is nothing more than moving alternate columns of water and air up the hole, should be avoided as a continuous operation. Too little air volume is the primary cause of slug drilling. For a proper mist drilling operation, enough air volume should be available to keep the hole clean and continuously unloaded.

Drill cuttings not removed fall back and bridge when connections are made. When this condition exists, several things can be done: (1) add more air volume, (2) sweep the hole with a soap slug just prior

ESTIMATED PENETRATION RATE - 50 FT. PER HOUR

Hole Size	Drill Pipe	Depth and Volume Required S.C.F.M. 1000	2000	4000	6000	8000	10000	12000
	6 5/8	6150	6600	7150	7700	8400	8950	9500
17 1/2	5 1/2	6450	6700	7400	8000	8550	9100	9650
	4 1/2	6600	6850	7550	8100	8700	9250	9800
	6 5/8	2600	2800	3000	3400	3700	4150	4500
12 1/4	5 1/2	3000	3100	3350	3900	4300	4700	5000
	4 1/2	3100	3350	3700	4200	4500	4900	5400
	6 5/8	2000	2150	2350	2650	3200	3550	3900
11	5 1/2	2300	2400	2700	3000	3300	3700	4000
	4 1/2	2500	2600	2900	3200	3400	3800	4100
	5 1/2	1700	1950	2150	2400	2600	2850	3100
9 7/8	5	1900	2000	2300	2600	3000	3300	3600
	4 1/2	1950	2100	2400	2700	3200	3500	4000
	5	1450	1550	1850	2150	2350	2550	2850
9	4 1/2	1550	1700	2000	2300	2500	2700	3000
	3 1/2	1700	1850	2200	2600	2700	3000	3300
	5	1350	1500	1700	2000	2200	2400	2700
8 3/4	4 1/2	1450	1650	1850	2140	2400	2600	2850
	3 1/2	1600	1750	2000	2280	2600	2800	3000
	4 1/2	1100	1200	1500	1800	2100	2350	2650
7 7/8	3 1/2	1300	1400	1650	1900	2120	2400	2700
7 3/8	3 1/2	1070	1150	1300	1550	1800	1950	2150
6 3/4	3 1/2	850	1000	1200	1420	1650	1850	2100
	3 1/2	710	790	930	1030	1280	1420	1650
6 1/4	2 7/8	790	850	970	1150	1420	1700	1800
4 3/4	2 7/8	430	500	650	790	930	1070	1200

TABLE 1—AIR REQUIREMENTS

to making connection. An increase in soap concentration will create a stiffer foam which can better clean the hole and remove the heavier drill cutting, and (3) always blow the hole until the return mist and air are clean prior to making connections. These simple procedures can eliminate a stuck drill string.

When the influx of formation water becomes too great to handle by mist drilling or when lost circulation is a problem, aerated fluid drilling is used to reduce the density of the return fluid column and hydrostatic pressure on the formation by injecting air and fluid into the standpipe simultaneously.

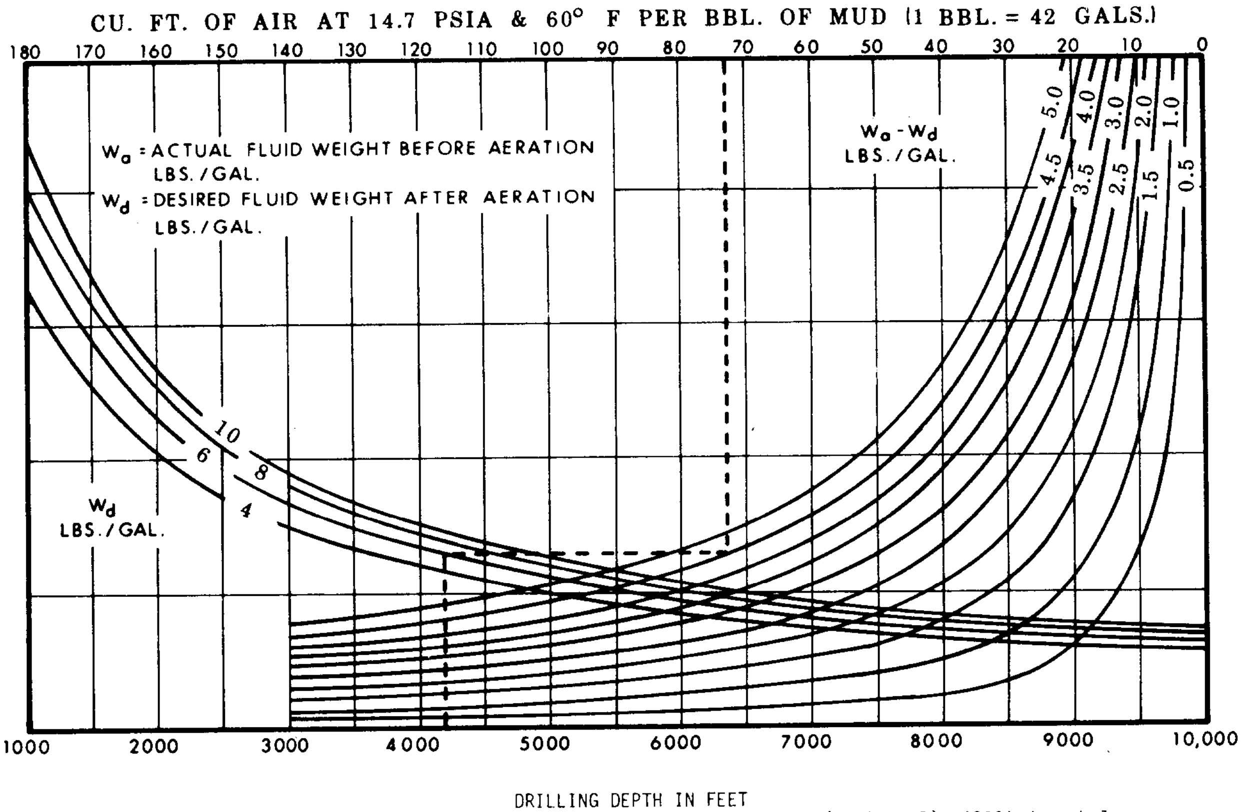
Air volumes used for aeration are smaller than those used for dusting or misting and are thought of in cubic feet of air per barrel of mud. Figure 13 provides a way to estimate the air volume requirements for aeration.

The required air volume for proper aeration of a fluid column can be controlled with jet subs and by regulating air volume.

The ideal aerated fluid combines air and fluid into a stable, homogeneous foam that does not break down and separate until it reaches the pits on the surface. The air must break out at the surface prior to reaching the mud pumps.

Unloading and Drying the Hole

The method, proven in actual field operations, to unload the hole of fluid, dry the hole, and start air dust drilling is given below.



TO FIND AIR REQUIREMENTS	1)	Find drilling depth in feet on bottom scale.	EXAMPLE (Follow Dotted Lines)	1) 4200' deep hole
	2)	Go up to appropriate curve of Desired Fluid Weight After Aeration (W_d).		2) Up to 6 lb./gal. Desired Fluid Weight After Aeration.
	3)	Go across to the appropriate curve of the difference between the Actual Fluid Weight Before Aeration and the Desired Fluid Weight After Aeration (W_a-W_d).		3) Over to 4.5 lb./gal. (10.5 lb./gal. Actual Fluid Weight minus 6 lb./gal. Desired Fluid Weight).
	4)	Go up to the Cubic Feet of Air needed per Barrel of Mud on top scale		4) Up to 73 Cubic Feet of Air

FIG. 13—REDUCING FLUID WEIGHTS BY AERATION, AVERAGE FLUID COLUMN TEMPERATURE 125°-175° F (POETTMANN AND REGMAN)

1. Run the drill string, complete with desired drilling bottom hole assembly and bit, to bottom.
2. Start mud pump and run as slow as possible. Pump fluid at a rate of 1-1/2 to 2 BPM. This may necessitate crippling the pump to get this rate. This is done to reduce fluid friction pressures to a minimum and pump at a minimum standpipe pressure for circulation. Standard fluid hydraulic calculations will indicate what the standpipe pressure should be at 1-1/2 to 2 BPM.
3. Bring one compressor and booster on line. This will aerate the fluid being pumped down the hole. About 100 to 150 MSCF per barrel of fluid should be sufficient for aeration. If too much air volume is being used, the standpipe pressure will exceed the pressure rating of the compressor, the booster, or both. Therefore, slow the compressor down until air is being injected and mixed with the fluid going downhole.

   Also, the mist pump and soap injection pump should be injecting water and soap at a rate of about 12 bbl/hr and 3 gal/hr, respectively. The soap will tie the fluid and air together and provide better aeration properties.
4. As the annular fluid column is lightened, the standpipe pressure will drop and additional compressors or air volume can be added to further lighten the fluid column and unload the hole.

   The aeration procedure is far superior when compared to the slug method of unloading the hole. The slug method is accomplished by pumping alternate slugs of water and air down the hole until air can be used continuously. Air is first injected up to an arbitary maximum pressure; then water is injected to lower the pressure back to some arbitrary minimum pressure. This procedure is repeated until air can be injected continuously. The aeration procedure requires less time, does not cause undue surging of the hole due to heading, does not cut out pit walls because surges are eliminated, and can be done generally at lower operating pressures.
5. When the hole is unloaded, the mist pump and soap injection pump should remain in operation. This provides a must (using 1-1/2 barrels of water per hour per inch of hole diameter and 1/2 to 4 gallons of soap per hour) which can clean the hole of sloughing formations.
6. At this point drilling, the use of air mist can commence. Drill 20 to 100 feet to allow any sloughing hole to be cleaned up.
7. After the hole has stabilized (no sloughing), stop drilling and blow the hole with air mist to clean the hole of drill cuttings. About 15 to 20 minutes is sufficient or until the air mist is clean. Clean air mist is usually a fine spray and white in color.
8. When the hole is clean, stop air misting, break off the kelly and pour 10 to 20 gallons of soap followed by 2 to 4 barrels of water directly down the drill pipe. Do not mix soap and water in mist pump and inject it that way. Pouring the soap and water directly down the drill pipe has proven to be a better procedure and gives a better soap slug and a greater drying effect.
9. Put the kelly back on and set the bit on bottom. Since the hole is now full of air, the soap and water will run to bottom. A proper soap sweep cannot be achieved unless it is mixed with air and pumped up the annulus. This cannot be done if the drill bit is above the soap and water.
10. With the bit directly on bottom, start air down the hole. Pump straight air at normal drilling volumes until the soap sweep comes to the surface. The soap will appear at the end of the blooie line and look like shaving cream.
11. Continue to blow the hole with air for about 1/2 to 1 hour.
12. Start drilling and the hole should dust after 5 to 10 feet have been drilled. Sometimes as much as 60 to 90 feet are required for dust to appear at the surface.

If the hole does not dust after this procedure has been followed, pump another soap slug around (starting at step 8). If a dusting condition cannot be achieved, mist drilling may be necessary.

Depending on the depth, this procedure, from start to dusting, requires about 2 to 6 hours. Holes have been unloaded using the aeration method, from depths of over 11,000 feet. Also, a well can be dusted, mist drilled, dried up, and returned to dust drilling. The key to drying a hole is to have it clean.

In some cases, drying agents have been tried with little success. To date, the best drying agent available is in the hole below the drill bit. Formation is an excellent drying material.

Downhole Problems

As mentioned earlier, out-of-gauge bits are a serious problem. Bits which offer the most gauge protection are used to achieve longer bit life and minimize reaming long sections of hole. Over-sized insert air bits, on today's market, can eliminate reaming and pinched bits. For example, an 8-inch mining-type air bit can be run first. The 8-inch bit can be pulled 1/8-inch out of gauge and still be followed by 7-7/8-inch without any risk of a pinched bit condition due to reaming.

Ball and roller, non-sealed type bits, not specifically designed to be used for air drilling, will pack dust (drill cuttings) in the bearings and lock the cones. For this reason, this type bit is not desirable for air dust drilling. The non-sealed bit, however, can be used when air misting. Other bit types such as journal or sealed-bearing bits have been used with satisfactory results in all air drilling operations.

One of the most common mistakes is starting to drill as soon as the bit hits bottom. It is vital to keep air flow so that initial cutting build-up is prevented and bearings are kept cool and clean.

Hole deviation can be a serious problem in any drilling operation. In this regard, deviation can be controlled, in most cases, in air-drilled holes through the use and proper application of two basic principles. These principles are the "pendulum effect" and the "packed or stiff hole assembly." The tools necessary to effectively carry out either of these two principles are available on today's market. Some of these tools are: (1) square drill collar, (2) reamers - - string and near bit, (3) stabilizers with tungsten-carbide insert replaceable wiper pads, (4) air percussion hammers, and (5) large diameter round drill collars.

The packed or stiff hole drilling assembly has been found most effective in air drilling. The stiff assembly should be used to eliminate or minimize doglegs. If drilling off the lease is not a problem, the hole should be allowed to deviate. This procedure has provided the lowest cost holes possible when air drilling wells with total depth of 8,000 to 10,000 feet.

On the other hand, deviation should be controlled in the upper part of the hole when drilling deeper air holes. Doglegs in the upper hole create excessive drag and excessive wear on drill pipe and tool joints. This is especially true as the well is drilled deeper.

The bottom hole square drill collar, with its inherent higher rigidity, provides three advantages: (1) deviation control (square collars add 60 percent more strength than round collars and help avoid doglegging), (2) a reaming effect behind the bit, and (3) indication of bit outside-diameter wear. Square collars are 1/16-inch smaller on diagonal than the bit gauge so that any unusual torque build-up will alert a driller to possible wear on bit gauge.

Square collars will inherently wear at the bottom and top of the collar. In order to minimize this wear, tungsten carbide inserts, tungsten carbide pads, or both have been placed in these areas of excessive wear. These inserts and pads, 12 to 18 inches in length, extend the usable life of the square collar.

The stabilizer with tungsten carbide insert replaceable wiper pads is essentially a short square collar. The advantage to this tool is that the wiper pads can be replaced in the field.

An excellent tool, proven in actual operations, to control severe deviation and maintain a straight hole, is the air percussion hammer. This tool is used to maintain a straight hole and achieve a reasonable penetration rate while running light weight (1000 to 5000 lbs.) on the bit. The air hammer is used in conjunction with the "pendulum effect." To accomplish this, a stabilizer usually is run 60 feet above the bit. The placement of the reamer will depend on the size of the drill collar being used. The reason for this is that a greater "pendulum effect" or lateral force on the bit can be achieved due to the stiffness of the various-size drill collars.

When an air hammer is being used, there are several techniques which should be used to ensure a successful run. To prevent plugging the air hammer, remove all rust and flakes from inside non-internally coated drill pipe by rattling the drill pipe and dope the pin end and not the box when running drill collars and drill pipe in the hole. To prevent the air hammer from coming unscrewed while going in the hole, make up each connection drill collar tight. Also, the air hammer should be tested on the rig floor, using the air volume normally used for drilling. Note the pressure at which the air hammer operates at the normal drilling air volume. This will allow any malfunction in the operation of the air hammer to be detected while drilling. The operation of the air hammer should be checked periodically. Stop drilling, leave weight on the bit and air on the hole, place a steel object against the kelly and near the ear and listen; a faint buzzing sound will be heard if the air hammer is working properly. Air hammer manufacturers recommend pouring a small amount of oil down the drill pipe periodically to lubricate the moving parts of the air hammer. With proper care and handling, an air hammer can run 150 to 300 hours.

Bottom hole drilling assemblies which are being used to control deviation in air drilling are illustrated in Figure 14.

Drill-pipe and drill-collar wear in air-drilled holes does not appear excessive and may even be less than wear in mud-drilled holes. For example, one string of pipe has been in continuous air drilling service for 1-1/2 years with over 380,000 feet of cumulative hole,and annular air velocities have been 9000 FPM. This string of 4-1/2 inch, 16.60 pounds, Grade E, X-hole drill pipe reflects a minimum wear of 0.067 inch (20 percent) loss of tube wall thickness, 0.53-inch (9 percent) loss of tool joint OD, and 0.31-inch (57 percent) loss of shoulder width. A periodic inspection of drill pipe is good drilling practice because drill pipe failure in an air hole can result in a junked hole. The inspection of this string of drill pipe revealed that (297 joints 91 percent of 327 joints) were still premium pipe. Ten joints were rejected due to thin average wall thickness. This particular string of drill pipe is internally coated and hard-banded.

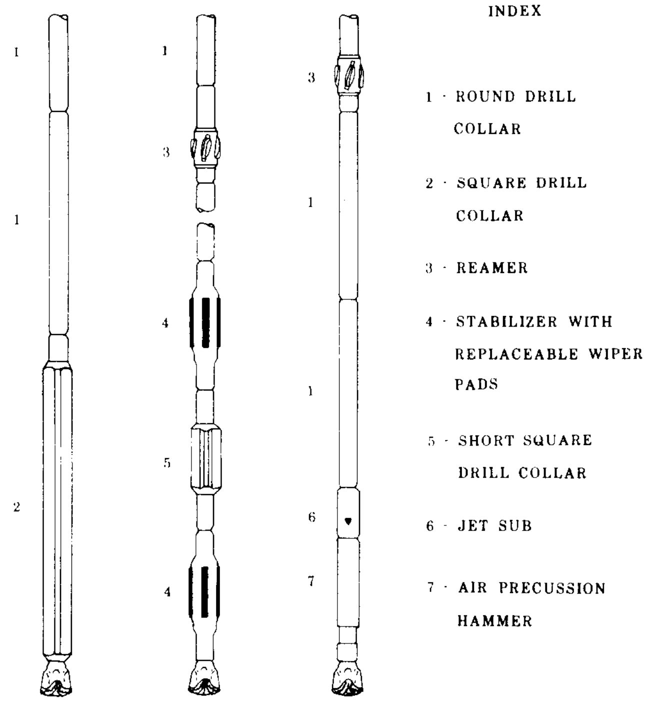


FIG. 14—BOTTOM HOLE ASSEMBLIES FOR DEVIATION CONTROL

A drill pipe string has been known to have been in continuous air drilling operation for about 1,000,000 feet before being replaced. This is probably an example of maximum drill pipe use in air drilling. However, this does point out that air drilling is not excessively damaging to drill pipe if proper precautions and handling techniques are employed.

Air drilling evidence has shown that drill pipe erosion can occur between the hard band and the tool joint metal when the box end is hard-banded. This erosion is due to drill cutting bombardment, which is similar to sand blasting. This type erosion can affect the life of a joint of drill pipe.

Design work for drill pipe to be used for air drilling has not kept pace with other advances in the technology. Maybe, if hard-banded drill pipe is desirable, the hard band should be put on the pin end rather than the box end, thereby minimizing tool joint wear due to erosion at the hard-band, tool-joint interface. This may require longer tool joints.

Excessive wear on a square collar can cause deviation problems due to changes in bending and stabilization characteristics. Therefore, a square collar should not be allowed to wear excessively before changing it out.

The fact that a square drill collar was used ahead of the above-mentioned drill pipe helps explain the exceptional performance of this string of pipe. Square drill collars minimize doglegs, and doglegs wear drill pipe. This is particularly true when doglegs are in a sharp, abrasive sand.

Air drilling in any form requires 24-hour supervision. Constant supervision must be maintained because trouble can occur quickly and compound so fast that air drilling economics are lost and expensive fishing operations result.

Avoiding problems and expensive fishing operations can be accomplished through proper supervision and application of proven air drilling techniques. For example, to avoid running bit cones off, bit torque should be monitored continuously. Checking hole torque off bottom and bit torque on bottom will provide an accurate measure of a bit's ability to turn properly.

Insufficient air volume to clean the hole can and does result in stuck drill strings. This problem is most likely to occur while mist drilling or because of sloughing of wet or dry sands and shales.

The lack of any buoyancy effect in an air hole creates dead loads of from 10 to 30 percent greater than in fluid filled holes. Drag, caused by friction between the drill string and the hole, further compounds these dead loads. Abnormal drag is dangerous and a possible sign of pending trouble such as a stuck or parted drill string. This type of drag occurs when the hole is not being cleaned and cutting load is building up, or when a sloughing hole condition is present and large chunks of formation are wedged between the hole and drill string or excessive doglegging exists.

When an abnormal drag condition exists, it is possible that the drill string will become stuck. In order to prevent the drill string from becoming stuck due to pulling into and packing dry drill cuttings, never pull on the string without air circulation. The air will keep the cuttings moving and allow them to work past the drill string.

Should the drill string become stuck, excessive pulling usually will not help free the pipe. A good practice, proven in several field operations, is to blow the pipe free with nitrogen under high pressure. This operation is easily accomplished with liquid nitrogen available for oil field use. Also, this procedure will only work if the drill string has not been pulled excessively and the cuttings packed tight.

Hole drag and torque can be minimized by using graphite for lubrication. Dry chemical injectors are available to inject graphite directly into the air stream.

A hole can occur in the drill string while drilling. This very dangerous condition is noted by a drop in standpipe pressure. When this occurs, stop drilling and set weight on the bit. Leaving bottom with a partially-parted drill string may result in expensive fishing operations or a junked hole. There is little chance to recover the dropped pipe due to the cork-screwing and breaking of the drill string. Also, any attempt to try to part the drill string with the bit on bottom can produce the same results as dropping the string.

A procedure, proven in field operations, is to set the bit on bottom, locate the hole by reverse circulating and running a horizontal spinner survey. By knowing the exact depth of the hole, the drill string can be set in a neutral weight position and backed-off below the hole. After back-off is accomplished, the string can be fished with conventional methods.

Water entry into the hole is a major deterrent to an air drilling operation. The degree of wetness ranges from dampness to water flows. Damp or partially wet conditions can be dried-up by using soap slugs mentioned earlier. As long as a drilling operation is continuous, the hole should remain relatively dry. However, after each trip, the hole may have to be redried.

Large water flows may require aeration for air drilling operations to continue. Should a water flow be drilled into, indicated by increase in standpipe pressure and loss of drill string weight, the drill string should be pulled immediately under certain conditions. The reason for this is to prevent sticking of the drill string caused by sloughing, water-sensitive shales when the formation water is relatively fresh.

Many materials such as cement, plastics, and chemicals are capable of shutting off water. The difficulty is in the proper evaluation of the water-producing zone and the ultimate ability to place the shut-off material where the desired results are achieved. Readjustment of the casing programs to fit air requirements is the answer to water shut-off in many areas.

When a hole makes water and it cannot be dried, mist or foam drilling should proceed by injecting a foaming agent into the air stream. A good foaming agent, soap, which generates a stable foam with enough film strength to keep the hole clean and relatively free of produced water should be used. A good rule of thumb is to inject 1-1/2 barrels of water per hour per inch of hole diameter plus 1/2 gallon to 6 gallons of soap per hour. Soap should be injected with a separate injection pump. The volume of soap should be kept at a minimum value sufficient to clean the hole. An increase in the concentration of soap gives the foam more stability and increases its carrying capacity.

Mist injection water should inhibit shales and the pH should be on the basic side. In some instances, corrosion inhibitor should be used. Depending upon conditions, particularly the volume of water flowing into the well, the concentration of soap may need to be changed. If insufficient soap is used, there will be considerable heading. If too much soap is used, the well will head with slugs of heavy foam and no liquid discharge. The lowest concentration of soap that gives a steady flow from the blooie line and a steady standpipe pressure is the amount desired.

Downhole Fires and Explosions — "Burn Offs"

It is a well-known fact that three conditions must be met in order to start a fire. There must be fuel, oxygen, and ignition or combustion. When gas is encountered during air drilling, the first two conditions are met — fuel in the form of natural gas and oxygen in the form of compressed air.

The main concern, when gas is encountered while drilling with air, is to prevent ignition. In order to do this, the causes of ignition while drilling with air must be known. Three things will cause ignition during an air drilling operation. These are (1) a "mud ring" (seal between bore hole and drill string), (2) downhole sparks, and (3) a small hole in the drill string.

Mud rings are the primary cause of ignition which causes downhole fires or "burn-offs." Ignition will occur, with proper fuel to air ratio, when a seal around the drilling assembly is formed. This seal is in the form of a "mud ring" created by drill cuttings and moisture. When the mud ring is formed, air circulation is stopped, and gas continues to accumulate in a pressure chamber, similar to the ignition chamber in a diesel engine. Ignition then occurs in this chamber when the gas-to-air ratio is in the 5- to 15-percent range, as shown in Figure 15. Therefore, by sealing off the air circulation and enriching the gas mixture, burn-off can occur with very small gas entries.

Based on actual experience from several downhole fires, data indicates that most burn-offs occur in the drill collar string. Also, most burn-offs occur at the top of the gas entry zone. In almost every case, at the time of a burn-off, the drill string has been stuck, indicating the presence of a mud ring.

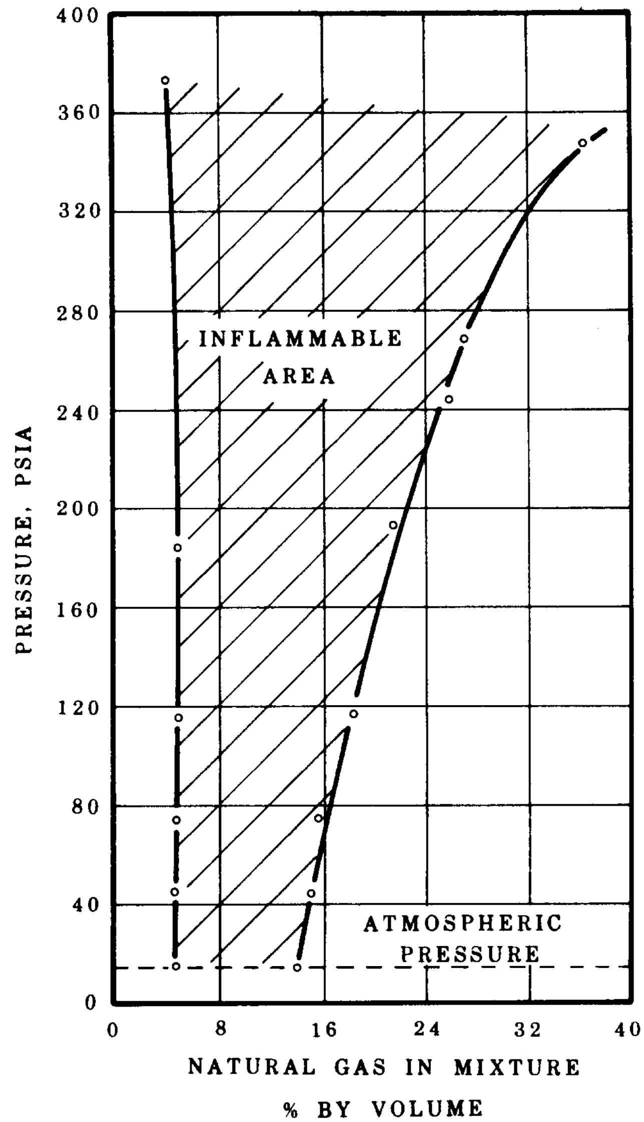


FIG. 15—EFFECT OF PRESSURE UPON THE LIMITS OF INFLAMMABILITY OF PITTSBURG NATURAL GAS (REPRINTED FROM BUREAU OF MINES REPORT OF INVESTIGATIONS 3798)

The two other sources of ignition for which there is little or no control while dust drilling are downhole sparks and small holes in the drill string. When drilling hard quartzite sands, sparks are caused when tungsten carbide bit inserts, drill collars, and drill pipe tool joints strike the hard face of the bore hole. These sparks are a source of ignition in the proper fuel-to-air mixture. The other source of ignition is a small pinpoint hole which can develop in a drill string. It has been demonstrated that when air (200 to 400 psig) is flowed through a pinpoint size hole that the friction drop across this hole creates enough heat to cause a hot spot. This hot spot can aid ignition of the right air-gas mixture.

Downhole fires and explosions cause extensive damage to the downhole equipment. Drill collars and pipe are melted and slag has been blown up-hole several hundred feet. Even though downhole equipment is damaged or destroyed, there is no damage to surface equipment. Most of the time all that is known at the surface is that the drill string is stuck, and a surface recording temperature survey may have to be run through drill string to determine if a fire occurred.

Because of damages incurred to downhole equipment after a burn-off, fishing operations are difficult and sidetrack operations are necessary in order to drill deeper. This type operation is expensive and time consuming. Therefore, the prevention of a downhole fire or explosion is of primary importance.

There are two positive methods to prevent downhole fires while drilling. The first is to drill with fluid. This method is much too expensive and slow for marginal gas plays. The second method is to drill potential pay zones with gas, also expensive at today's gas prices.
drilled through the pay. However, gas is not always available and drilling every potential gas pay with gas can be expensive and will be moreso as the price of natural gas goes up. At present, mist drilling is the most common method used in preventing a burn-off when gas is encountered.

There may be no absolute method to prevent a downhole fire while drilling with air; however, certain measures can be taken to lessen the chance of a burn-off. Constant supervision is an absolute necessity in any air drilling operation. This is especially true when air drilling a potential gas pay. Pressure recorders with high pressure alarms able to sense 5 to 10 psig increases in standpipe pressure are necessary. The pressure recorder denotes the formation of a mud ring or back pressure from gas entry through pressure increase on the standpipe.

When a gas show or an increase in standpipe pressure is noted, several steps must be taken to prevent a burn-off. These steps are:

I. Immediately stop drilling.
II. Shut air off and monitor gas flare.
   A. If gas flare sustains, determine whether or not gas is wet by noting:
      1. Wetness of cuttings at sample catcher.
      2. Black smoke and/or yellow color of burning gas, indicating distillate in gas.
      3. Sparks at end of "blooie line," indicating drill cuttings are damp with distillate.
   B. If gas flare will not sustain or burn with air off proceed to Step III.
III. Put air back on the hole and determine if gas is wet.
   A. Do not drill at this time, as new cuttings may form mud ring.
   B. With air on, pass tool joints to prevent the formation of a "mud ring."
IV. If gas is wet (water or distillate) as indicated in II-A, II-B, or III above, mist drill or drill with gas.
V. If gas is dry, or no sparks, no black smoke, or no wet samples at surface:
   A. Drill 5 to 10 feet.
   B. Pass tool joints to avoid pressure increase by mud rings.
   C. Continue to drill at 5 to 10 feet intervals until it is determined that a wet gas condition does not exist.

During all of the above steps, while the air is on the hole, monitor the standpipe pressure constantly. As long as the standpipe pressure is above normal drilling pressure, the prospects of a burn-off are good when gas is encountered. Remember—it takes only a very small amount of gas to ignite a burn-off when a mud ring is present.

Partial mud ring or closure in the annular space restricts air flow causing standpipe pressure to increase. Complete closure can occur quickly and will not be noted at the surface immediately due to the compressibility of air. For this reason, quick action is necessary to prevent a burn-off which starts with "stop drilling."

Assuming that drilling is not stopped when a gas show or pressure increase is noted, the following events will occur.

1. A small increase in standpipe pressure occurs.
2. Drill cuttings become damp due to distillate or water. These cuttings begin to pack together and form a mud ring around the drill string.

3. As the mud ring closes, pressure will further increase to the operating capacity of the compressor.
4. The drill string is stuck, indicating a mud ring is formed.
5. Ignition of a downhole fire then occurs. This ignition is similar to a diesel engine ignition.

Based on field experience of actual downhole fires, it requires no more than 40 feet of drill cuttings to generate enough dust to create a mud ring and ignite a burn-off.

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