# Automatic Jet Subs for Air Drilling

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## INTRODUCTION

The use of air or gas as a drilling fluid is perhaps the most significant contribution to drilling technology since rotary drilling. Laboratory and field tests have repeatedly shown that when liquid drilling fluids are replaced by air, drilling rates and bit life improve. (In this paper the term "air" includes natural or inert gas).

Air drilling has not received widespread application because of operational problems and equipment limitations. Formations that produce water cause the most serious problems. In the past, water in the borehole meant an end to air drilling. If borehole conditions permit, however, considerable volumes of produced water can be lifted from the wellbore by the air stream and air drilling can continue. In many cases, the economical application of air drilling when water-producing formations are exposed is precluded by another operational problem. During connections, trips, or other downtime, water accumulates in the borehole. This water must be removed before drilling can resume.

Several techniques can be used to remove the water, but all have disadvantages or limitations. If the rate of influx is not great, heads can be removed by staging into the hole. Water is unloaded in several steps starting near the top and working down. Staging can be quite slow and can work to offset gains in drilling rate. The water can be unloaded from the well in one step by blowing from bottom; but this method requires high surface pressures, is harmful to the borehole wall and to surface equipment, and is also time consuming. The technique of "rocking" can be used. Alternate slugs of air and liquid are pumped into the drill pipe until the head is aerated and will circulate. This is a very slow process.

A jet sub can be used. This sub provides a path for the air to enter the annulus above the bit and remove liquid. Jet subs allow quick circulation at lower pressure than required to unload from the bit. Jet subs available up to now were subs with a replaceable orifice opening in the side. These subs are helpful, but subs that are always open have a disadvantage. Part of the circulating air is continuously diverted through the sub during drilling. Continuous circulation through the sub starves the bit and erodes the borehole wall.

An automatic jet sub has been developed to circumvent this disadvantage and thereby provide a tool that will easily and quickly unload fluid heads.

## FEATURES OF AUTOMATIC JET SUB

The automatic jet sub is a spring-loaded differential pressure valve mounted in a drilling sub. Fig. 1 is a drawing of the valve assembly. The automatic jet sub has an advantage over fixed orifice subs. It is open when needed to unload liquid and closed when full circulation to the bit is possible. The differential pressure setting of the valve can be adjusted manually by changing compression on the spring. A discharge orifice provides flexibility in control of the volume of air that flows through the valve. The complete valve assembly is replaceable in the field.

## PRINCIPLES OF APPLICATION

The subs are spaced in the drilling string to divert some air to the annulus above the bit when needed. The location and number of subs and the spacing between them depend upon several variables associated with the particular operation. The capacity and pressure limit of the compressors or gas supply and the height and density of the maximum liquid head are the controlling factors. Subs can be located and spaced to enable rapid unloading of liquid with available compressor equipment without staging. The guiding principle on the pressure setting of the valves is that the lower the differential setting, the fewer valves are required. The minimum $\triangle P$ setting, however, is the estimated pressure drop across the bit jets plus some safety factor. Pressure settings less than the pressure drop across the bit will lead to the valves being open during normal dry air drilling. The total choke area of all valves in the string must not be enough to pass the total volume of air at maximum surface pressure. This ensures that the bit will not be completely starved of air if all valves open.

The correct installation of automatic valves in the drill string requires study of the existing conditions in the well.

## EXAMPLE APPLICATION

Assume a well 7000 ft deep has water standing at 3000 ft. To unload this fluid head from bottom would require about (4000 ft x .435 psi/ft) 1740 psi surface pressure. Assume maximum compressor output pressure is 1000 psi and that unloading in stages is not practical. A bit float valve is to be used. Pressure drop across the bit for normal dry air drilling is estimated at 100 psi; therefore, differential pressure setting of valves must be higher. The compressor can deliver 1500 cfm at maximum pressure.

The first step is to estimate the number of subs required. This can be done by using this equation:

$$N = \frac{.052\,(\rho f)\,H}{Pc + Pg - \Delta P_{bit} + 50} \qquad [1]$$

Where:
- $N$ = Number of subs required
- $\rho f$ = Density of liquid, lbs/gal
- $H$ = Height of liquid head, feet
- $Pc$ = Maximum surface pressure available, psi
- $Pg$ = Pressure effect of compressed gas column at depth when surface pressure = Pc, psi
- $\Delta P_{bit}$ = Estimated pressure drop at the bit for normal drilling, psi.

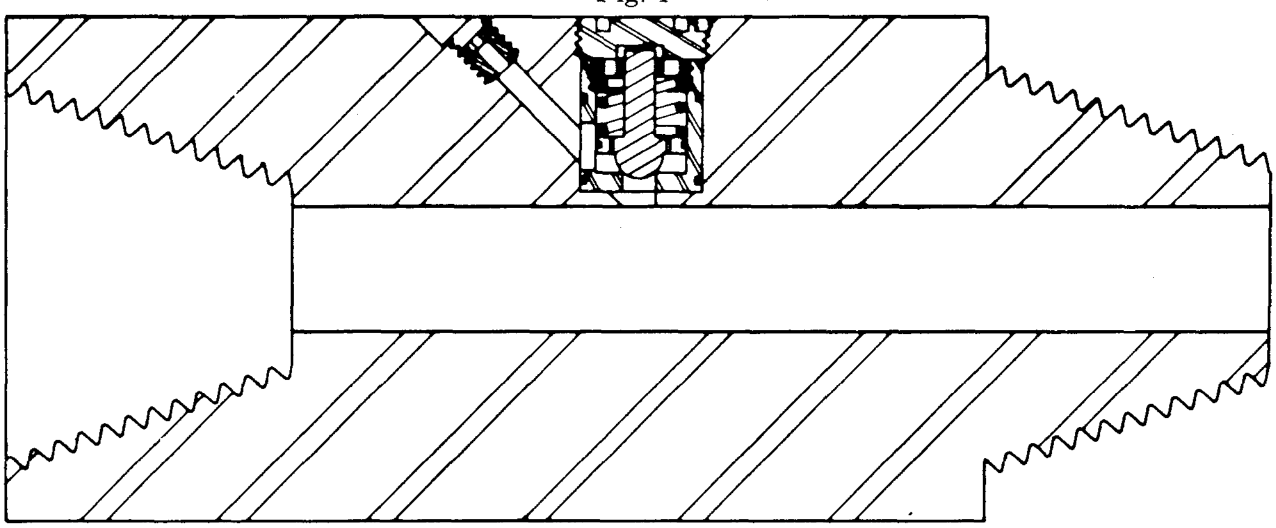
*The effect of the compressed gas column and the pressure drop across the bit will almost cancel and can be neglected in most cases.*

For the example well:

$$N = \frac{.052\,(8.4)\,(4000)}{1000} = 1.75$$

"N" can be rounded to the next lowest, whole number. One valve will be required for the example well to unload the fluid with the available compressor. Select a 200 psi differential pressure valve setting. Calculate the depth in the annulus where the pressure due to the fluid head is $Pc + Pg - \Delta P_{sub}$ (Surface pressure + pressure effect of compressed gas - differential pressure setting of valve.) Estimate Pg=350 psi for this case. So, 1000 + 350 - 200 = 1150 psi ÷ .435 = 2640 ft. 3000 + 2640 = 5640 ft.

Fig. 1



**AUTOMATIC JET SUB**

With the 200 psi valve set at 5600 ft, pressure will build in the drill pipe until the surface pressure reaches 1000 psi; the valve will open and the fluid above the valve in the annulus will be unloaded. When the fluid above the valve is unloaded, a portion of the air will continue to flow through the valve. The pressure in the drill pipe will not diminish because the air is being replaced faster than it can flow through one valve at the existing differential.

Because pressure in the drill pipe is greater than [(7000 - 5600) x .435] 610 psi, the bit float valve will open and air will circulate through the bit and unload the remainder of the fluid in the annulus. When drill pipe pressure drops below 200 psi, the jet sub valve will close. Full circulation will then be through the bit.

## VALVE ACTION DURING DRILLING

The mechanism of two-phase flow in the annulus is not well understood. Liquid flowing into the borehole while air is circulating is probably broken into a mist if the liquid volume is small. As liquid volume increases, the liquid begins to flow up the wall of the hole and the pipe in an annular ring. Circulating pressure increases slowly as this annular ring increases in thickness. At some point, the liquid volume may be large enough to form a slug of liquid. When a slug of liquid forms, pressure increases in the annulus beneath the slug. Velocity of the air decreases accordingly, and cuttings may fall out of the air stream. It is desirable to prevent the formation of slugs. As circulating pressures increase, the automatic jet sub will open and divert a portion of the air into the annulus to boost the flowing liquid toward the surface. When pressure goes down, the valve will close.

## MULTIPLE SUB INSTALLATIONS

Some situations may require more than one sub to unload a well. Assume the same well as in the previous case with compressors capable of 1500 cfm at only 500 psi maximum pressure. Equation 1 shows that three subs will be required.

The first sub, with a 250 psi differential, would be located at ($P_c + P_g - \Delta P = 500 + 150 - 250 =$ 400 psi $\div$ .435 psi/ft $=$ 920 ft $+$ 3000 ft $=$ 3920 ft) a depth of 3900 ft. The second valve, a 200 psi valve, would be located at (500 + 150 - 200 = 450 psi $\div$ .435 = 1035 ft + 3900) 4900 ft. The third sub with a 150 psi valve would be located at (500 + 150 - 150 = 500 psi $\div$ .435 = 1150 + 4900 = 6050) 6000 ft. With these three valves open, air input of 1500 cfm would result in a surface pressure of 500 psi and a pressure at the bit of about 650 psi. This pressure would be sufficient to open the bit float and unload the water below the deepest valve.

For estimation of pressure drop across an open valve, choke tables for 1/4 in. chokes can be used. If, for multiple sub installations, the pressure that can be built up across the valve by the volume of air available is not high enough, a discharge orifice smaller than 1/4 in. can be placed in the port as shown in Fig. 1.

## FIELD EXPERIENCE

Automatic jet subs have been used in the field on one occasion. A well 6800 ft deep had fluid standing at 3400 ft. Rate of fluid influx was so high that staging was not possible. Attempts to unload from bottom were unsuccessful. Compressor pressure built to 1300 psi, and the hole would not unload. A 250 psi differential jet sub was run at 4600 ft. A 150 psi differential sub was run at 5600 ft. Surface pressure built to 1000 psi, and the hole unloaded quickly and easily.

## FIELD MAINTENANCE

The valve assembly in the jet sub is completely replaceable in the field. Because drilling service is very hard on down-the-hole tools and erosion is a potential problem, it is anticipated that the condition of the valves will be checked and the valves replaced every trip if necessary.

## CONCLUSION

An automatic jet sub for air drilling has been developed. The use of these subs permits unloading of liquids from the wellbore with lower surface pressure than normally would be required.