Gas Kicks and Deep Well Drilling

BILL REHM
SWACO—Oil Field Division of Dresser Industries

In the deep high-pressure well, the reaction of the gas and the interaction of the gas and mud system are strongly affected by the critical pressure of the gas, borehole temperatures, and by the very long period of time that is required to circulate the system and to receive the transmitted pressures. As a result, there has been a certain amount of confusion about well control and detection methods. The basic rules that were first established by Goins and O'Brien[1] are still valid, but the surface mud flow, and drill pipe and casing pressures appear to show that something else is happening.

Since:

$$\text{Pressure (psi)} = D \times .052 \text{ Wt \#/gal}$$

$$\text{Wt \#/gal} = \frac{\text{Pressure (psi)}}{D \times .052}$$

and reciprocal of .052 = 19.2 or 20

$$Wt_2 = Wt_1 + \frac{\text{S.I.D.P.P.} \times 20}{D}$$

or

$$\Delta Wt = \frac{\text{S.I.D.P.P.} \times 20}{D} \quad \text{\#/gal}$$

for West Coast Convention (# /ft^3)

$$\Delta Wt = \frac{\text{S.I.D.P.P.} \times 150}{D} \quad \text{\#/ft}^3$$

FIGURE 1

MUD WEIGHT TO KILL A KICK

A REVIEW

When a well is shut in during a kick, the shut-in drill pipe pressure indicates the amount by which the reservoir pressure exceeds the pressure of the column of mud in the drill pipe. From this is derived the mud weight required to kill the well (Fig. 1).

To start circulation, it is assumed that the shut-in condition represents equilibrium with no further influx from the reservoir. Thus, if the well were initially circulated for a short period of time, holding the annulus pressure constant, annular equilibrium would be maintained. Circulation can then be initiated with confidence that a minimum overpressure is being used to dominate the reservoir.

Shortly after circulation is started, the control is switched. The annular pressure is allowed to vary and drill pipe pressure is kept constant. This avoids the problem of calculating gas expansion and washout in the wellbore. This is justified by accepting that shortly after the initiation of circulation, the drill pipe pressure represents the sum of the system pressure loss (pump pressure to circulate the well) and the Shut-in Drill Pipe Pressure, (SIDPP) (the extra pressure required to dominate the reservoir). After control is switched, the drill pipe pressure is kept constant unless the mud weight in the drill pipe is changed. If the mud weight is changed, the pressure exerted on the bottom of the hole by the new mud weight in the drill pipe must be added to or subtracted from the Constant Drill Pipe Pressure, (CDPP).

This is the CDPP technique that was first described by Goins and O'Brien. While there are minor variations [2,3,4,5,6] the basic concept is unchanged.

ANNULUS GAS

There are a number of reasons why SIDPP on the deep well may not appear to be a precise measurement. Often there is a considerable amount of gas-cut mud in the annulus from gas cutting in upper formations or from a low permeability reservoir. The gas in the annulus has three effects.

First, to develop a SIDPP that represents "the value by which the reservoir pressure exceeds the pressure exerted by the column of mud in the drill pipe", the reservoir must bleed enough gas into the annulus to pressure up to an equilibrium (Fig. 2). In the case of a low permeability reservoir, especially if the annular mud were badly gas cut, some considerable period of time may be required. This leads to some confusion in operations because the SIDPP does not appear to stabilize but continues to rise at about the same rate as the annulus pressure. In a case like this either a waiting period or the assumption of some ultimate pressure is required to avoid a value of SIDPP that is too low.

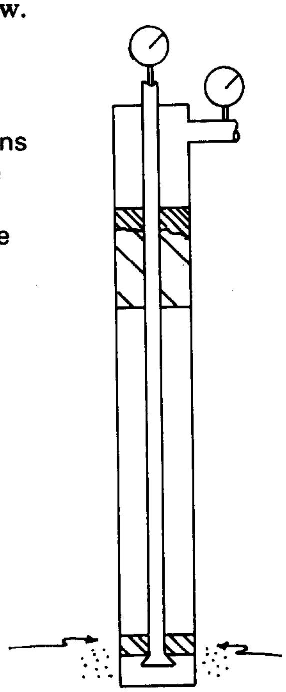

FIGURE 2

ANNULAR GAS MUST BE RE-COMPRESSED TO PROPERLY EXPRESS MAXIMUM PRESSURES

Repressuring of the wellbore has resulted in more genuine confusion and honest questions from the rig floor than any of the other problems that have occurred. The above explanation has been rephrased several times, and one of the better explanations to a rig crew includes most of the following elements: "When the kick occurs, the wellbore is partly emptied. This is represented by the increase in mud in the mud pits. The gas that takes the place of the mud in the annulus has expanded. So enough new gas must enter the wellbore from the reservoir to recompress some of the gas in the annulus (Fig. 2). Once the pressure in the hole builds up enough to balance the reservoir pressure, the drill pipe pressure will stop rising. This will happen quickly if the kick is caught early (the pit volume increase is small) or if the reservoir has good permeability. If the SIDPP rises very slowly, generally this is a good indication of low reservoir permeability. The reservoir is not good enough in its present condition to feed gas into the system quickly. In this case, as long as the well is circulated based on a good guess of SIDPP, there will not be enough gas work its way into the system to blow the well out."

This general explanation, while it serves in many cases, requires some judgment with very deep holes. With a very long column of gas-cut mud, it may take a considerable amount of time for the reservoir fluid to recompress all the gas in the hole. It is possible under deep hole conditions and long periods of time to lose track of pit volumes and pressure increases. Furthermore, the gas entering the deep hole is at greater than critical pressure, and acts like a liquid. Under the conditions of critical pressure it will take a considerable volume of liquid gas to significantly compress the gaseous phase up the hole.

The second problem occurs when enough gas has entered the annulus to unload the hole and reduce the bottomhole pressure. This is signaled by a large increase in flow from the flow line and a considerable pit volume increase. Under these conditions there will be a high shut-in annular pressure, and there is often an abnormally high SIDPP. Calculations from the SIDPP often will give a mud weight well in excess of the fracture pressure or even overburden pressure. This condition is not too uncommon and again leads to a question of the validity of the drill pipe pressure as an indicator or control for the reservoir pressure.

What has happened is that some of the mud in the drill pipe has drained out into the annulus and can no longer exert a downward pressure in the drill pipe. Normally it might be thought that the thrust of the reservoir pressure against the bottom of the drill pipe would keep it from draining. This is not necessarily the case. If a very rapid reduction in bottomhole pressure should take place, as when the hole unloads, the pressure in the annulus drops at a greater rate than can be replenished by many reservoir bodies. In this case, then, the column of mud in the drill pipe is heavier than the similar column in the annulus; or what is more important, it is heavier than the pressure drive from the reservoir can support. Mud then drains out of the drill pipe until a pressure balance is re-established by the influx from the reservoir. At that time, the drill pipe is no longer full, and the drill pipe pressure gauge reports a very high shut-in drill pipe pressure (Fig. 3).

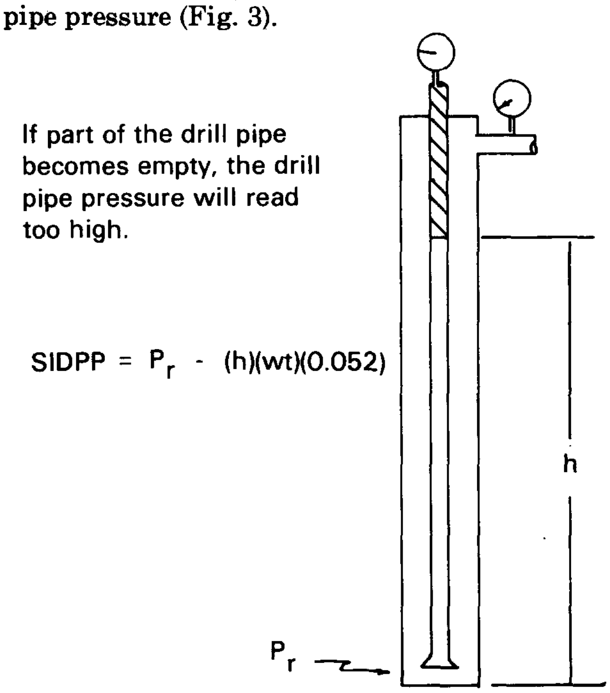

FIGURE 3

CORRECT SIDPP DEPENDS ON THE DRILL PIPE BEING FULL OF MUD

The erroneous conclusion often reached is that the drill pipe pressure reading must be wrong. It is not; it is simply reporting what the shut-in drill pipe pressure always reports: "The amount by which the reservoir pressure exceeds the pressure exerted by the column of mud in the drill pipe". If there is a question about the apparent validity of a high SIDPP, the casing pressure should be held constant by choke adjustment while some mud is pumped down the drill pipe. Then the well should be shut in again. The addition of mud will cause the second SIDPP to be lower than the original value. When this occurs, a casing pressure schedule must be established for the initial part of the kill procedure since a constant casing pressure for a period long enough to fill the drill pipe would probably cause lost circulation.

The volumetric method of developing the annulus pressure value would probably work best in this case. The volumetric casing pressure method utilizes the mud displaced from the hole converted to psi/bbl as a control. If the mud volume in the pits gains, then the volume gain corrected to psi/bbl is added to casing pressure to maintain constant bottomhole pressure. (Fig. 4)

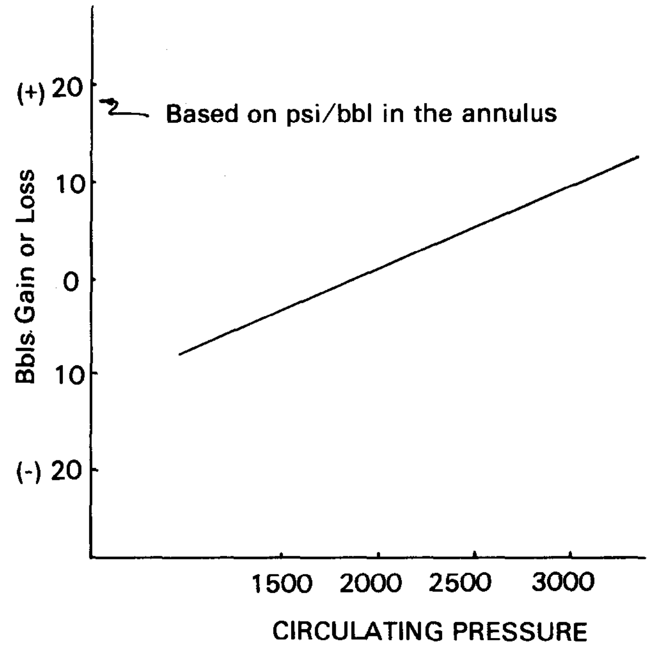

FIGURE 4

VOLUMETRIC TABLE

The third problem that relates to annular gas is pressure lag. When using drill pipe pressure as a control, the choke at the annulus may be as much as seven or eight miles away from the pressure gauge. This induces a delay in the response of the drill pipe pressure gauge to the action of the choke. In a cased hole containing only fluid, the delay does not much exceed the theoretical value of a velocity of 5000 to 6000 ft/sec. However, in an open hole containing gas, the delay more closely approaches 1000 ft/sec (Fig. 5). In the case of a 20,000-ft hole this would indicate a lag period of about 40 seconds between the operation of the choke and the reflection of it on the standpipe pressure gauge. The apparent low velocity is due to having to compress or expand the gas in the wellbore to express the proper pressure. It is evident from this that the lag in pressure transmission is related to the size of the gas kick and the position of the gas in the annulus.

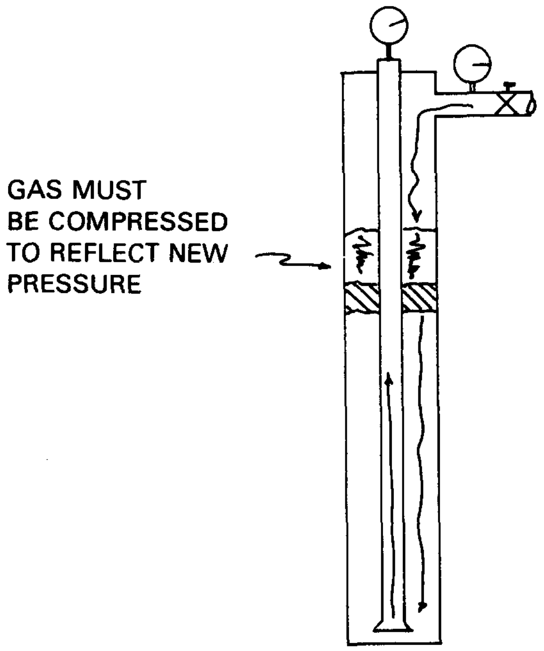

FIGURE 5

GAS COMPRESSION SLOWS RESPONSE OF DRILL PIPE PRESSURE GAGE

Pressure lag then is a variable that does not lend itself to an exact solution. With an inexperienced operator at the choke control, this can be a serious problem. In attempting to "chase the pressures", the entire concept of constant bottomhole pressure can be badly confused and the whole operation can collapse in frustration. The only reasonable procedure is to change the annulus pressure by the desired increment when a change is required on the drill pipe pressure gauge. Then wait for some reasonable period of time. Mathematical models[2,8] indicate that with a wellbore that contains gas, any change on the annulus pressure gauge will reflect as between that change and one half of that change in pressure on the drill pipe gauge.

HIGH ANNULUS PRESSURE

An annulus pressure curve can be developed using Bartlett's[5] method that is reasonably simple to develop and is particularly valuable in preparing for some of the problems that occur in very deep wells. The curve, Fig. 6, indicates that in the deep well, the annulus pressure is generally quite high, due to a small diameter hole, and continues to remain high with little variation for a long period of time. This again leads to the belief that the system is not working. Several wells have been fractured when too much pressure was introduced into the well because the annulus pressure stayed high for so long that the operating people felt that gas must be still entering the wellbore. Not only does it take a long time to kill a kick in a deep well, but the annular pressure stays high for almost the entire period.

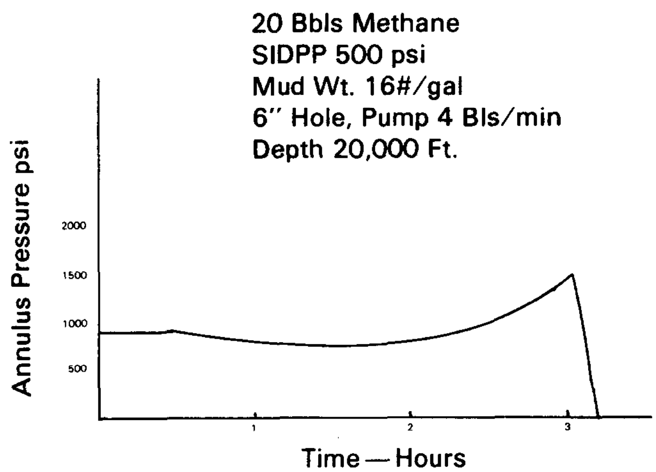

FIGURE 6

ANNULUS PRESSURE STAYS HIGH DURING A GAS KICK IN VERY DEEP HOLES

The high annular pressure also induces another difficulty that relates in particular to casing design. In normal depth wells, it can be generally assumed that with a kick, the weakest point in the wellbore is just below the casing shoe. In the very deep well, there is an interval halfway[9] down the hole that develops very high gradient pressures because of the geometry of the gas bubble and pressures impressed at the surface. Unfortunately, this is also the point where the lightest casing in the string is to be found. There have been a number of deep wells that have had casing split during a well kick as a result of this mechanism. Certainly the problem of the induced pressures from well kicks should be considered during casing design on a deep well.

THE EFFECT OF VARIOUS GASES

Most literature concerning blowout control assumes methane as the intruding gas since methane, the lightest of the hydrocarbon gases, has the greatest expansion and the highest critical pressure. Any hydrocarbon gas heavier than methane does not show as great an expansion. As the gas gets heavier, gas kick conditions more closely approach the values to be expected from an oil or salt water flow. There is, however, a significant difference in the reaction from hydrogen sulfide and carbon dioxide found in the deep reservoirs that are now being penetrated. Figures 7 and 7-A compare the effect of methane and hydrogen sulfide, assuming a five-barrel kick in a 20,000-ft hole that was swabbed-in during a connection. Notice, under the conditions set forth, that the methane gives a higher pressure reading than H_2S, but that it gives about a one-hour warning. The methane curve starts to show an increase in flow and in pit volume when it is only half way up the hole, reflecting that the critical pressure, or the pressure below which it starts to show expansion, is in the 6000 psi to 8000 psi range. Note, however, the effect of hydrogen sulfide. The hydrogen sulfide has a critical pressure in the range of 1000 psi so it doesn't start to expand until it gets very close to the top of the hole. It gives very little warning and starts to unload the hole very rapidly. This is one of the reasons that there has been so much comment about hydrogen sulfide kicks giving little or no warning. Notice in this case that the hole would unload completely in about six minutes. Generally, it is accepted that it takes an alert crew at least a minute to close preventors.

To add to this problem, hydrogen sulfide and carbon dioxide are quite soluble in muds and this solubility allows a greater volume of gas in the mud without showing a great effect at the surface. When the hole unloads, some of the gas solution is released and adds to the intensity of the kick. This problem can be very critical in the case of oil muds where solubility can become an overriding function.

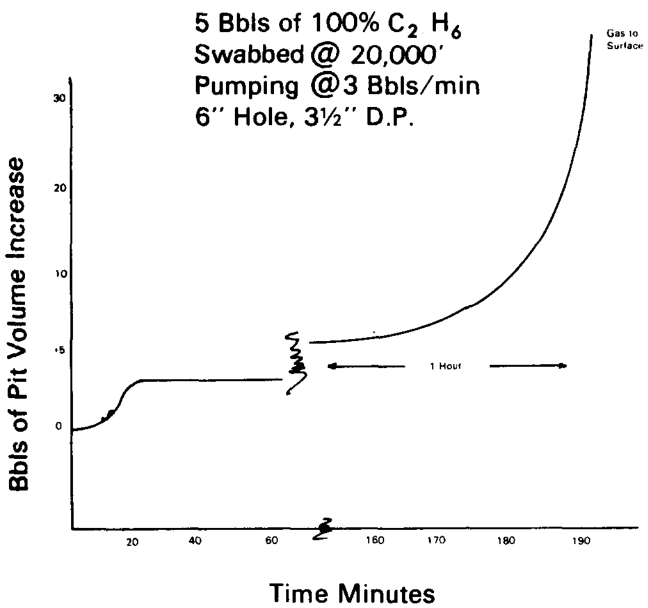

FIGURE 7

A TYPE EXAMPLE OF METHANE SWAB GAS

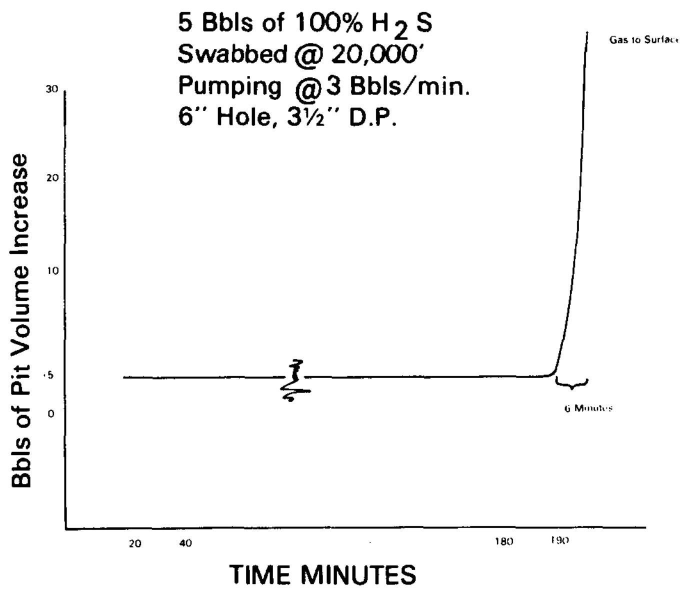

FIGURE 7-A

A TYPE EXAMPLE OF H_2S SWAB GAS

CONCLUSION

The gas kick in a very deep well can appear different from a similar problem in a 10,000-ft well. While some of the differences have been cataloged as separate and distinct phenomena, the situations tend to combine and problems intensify. The solution lies in an understanding of the problems with gas under high pressure and keeping the gas kick as small as possible.

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