

UNDERGROUND BLOWOUT TRAINING MODULES

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Executive Summary

This LSU study was funded by the Minerals Management Services U.S. Department of the Interior, Washington, D.C., under Contract Number 14-35-001-30749. This report has not been reviewed by the Minerals Management Service or been approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Service, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The overall goal of this MMS well control research project was the development of improved procedures for detecting and handling underground blowouts in marine environments. The goal of this task, Task 10, was to create four training modules based on the post-analysis of case histories of actual underground blowouts or near misses. The concept was to provide learning tied explicitly to real field experience rather than to reliance on theories or logic.

This report documents four training modules on how to avoid and to correct underground blowouts. The modules are included as Appendices A, B, C, and D, and are described in the chapter entitled “training modules.” The four modules are based on case histories, which are described in the chapter entitled “Underground Blowout Case Histories.” The first module is an interactive, group learning exercise based on the case history of an underground flow offshore Texas. Participants consider alternative actions at key decision points and the expected consequences of those actions, and then review what actually happened. The second module is an interactive, computer-based, programmed learning exercise. It is based on the same case history and requires similar decision-making by the participant, but does not require an instructor or group discussion. The third and fourth modules are computer-based training simulations. The third uses a simulation of a hard-to-detect, swabbed-in kick to reinforce the importance of careful monitoring and proper, timely reactions as a key to preventing the large kicks that often cause underground blowouts. It is based on swabbed-in kicks that were the causes of an underground blowout in a deep gas well and a near miss. The last module is a simulation that recreates the conditions for a kick taken while drilling with a low kick tolerance. It provides a basis for both reinforcing the importance of rapid identification and control of a kick in these circumstances and for practicing the non-routine methods required when lost returns occur after shutting a well in on a kick.

Introduction

The Minerals Management Service is concerned about reducing the potential for surface and underground blowouts because Congress has mandated that MMS is responsible for worker safety and environmental protection.

The 1994 –1999 LSU/MMS well control research project was proposed by Bourgoyne and Kelly¹ to focus on the development of improved procedures for detecting and handling underground blowouts in marine environments. Task 10 of the project was proposed to post-analyze, and to create training modules based on, case histories of underground blowouts.

The specific objective of this task has been to develop training modules to support industry training on how to avoid and to correct underground blowouts. This training must include both field operations and engineering support personnel because of the complexity of most underground blowout control operations. Consequently, the modules are intended to meet the training needs of both field and office personnel. The purpose of this report is to deliver the modules, describe the learnings from the case histories used, describe how the modules are used, and document the results of training industry personnel and university students using several of the modules.

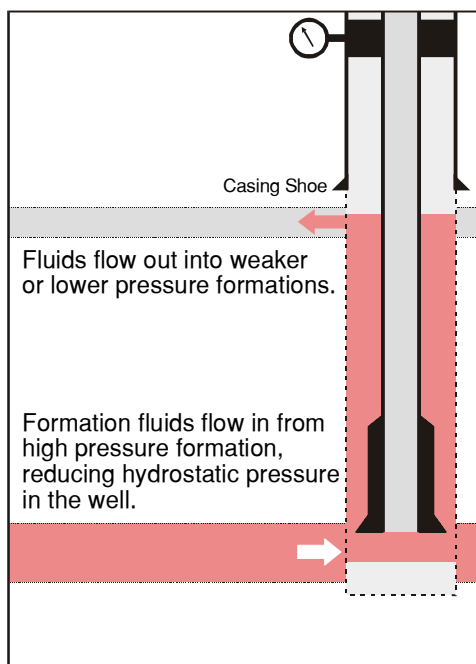


Figure 1 – Example of Underground Blowout

Description of Underground Blowouts

An underground blowout occurs when formation fluids flow from one subsurface zone to another in an uncontrolled manner (Figure 1). The results range from being indiscernible to catastrophic. An underground blowout can result in minor subsurface transfers of fluids that may never be identified or in flow which reaches the sea floor or ground surface. If the flow reaches the surface, a crater, a fire, loss of equipment, and sometimes loss of life may result. Extreme examples have resulted in complete loss of offshore platforms and all components of large land drilling rigs.

A principal difficulty in handling underground blowouts is the difficulty in diagnosing and understanding what is actually happening in the subsurface. Assessing the risk of cratering can be especially difficult. Consequently,

determining what the best remedial action might be and what consequences may result from unsuccessful actions are also difficult. Robert D. Grace⁵ provides a similar assessment of the challenges and complications relating to underground blowouts in his book on advanced blowout and well control.

These difficulties are exacerbated by the lack of a systematic approach for analyzing and controlling the flow. Although at least one operator developed an internal set of systematic guidelines, this shortcoming is evident in the relative lack of coverage of underground blowouts in conventional industry well control training. This difficult and complex subject usually accounts for much less than 5% of the time or material covered. Some of the training resources, that do exist, refer to methods, such as the “low choke pressure” method, that may cause or increase the severity of an underground blowout. Overall, there are shortcomings in all areas relating to underground blowouts: training, prevention, identification, diagnosis, control, and verification of control.

OVERVIEW OF PROBLEM

Current industry practices for remedying underground blowouts are poorly defined. Consequently, industry training courses typically lack comprehensive coverage on avoiding the causes of and implementing the cures for underground blowouts.

Causes

An underground blowout is initiated when the pressure-containment capability of a wellbore containing formation fluids is exceeded by the wellbore pressure anywhere in the well. The limit on pressure-containment capability is typically the formation fracture gradient at the exposed casing shoe, but objectively, it is whatever point in the wellbore that is weakest for the given conditions. It could be a low fracture gradient elsewhere in the open hole, a lost circulation zone, or a low strength or damaged portion of the casing.

The underground blowouts reviewed herein all occurred during drilling operations. The potential for an underground blowout is commonly greater in a drilling well than in a production well. The production casing in a production well protects both the formations and shallower casing strings that have less pressure capability than the production casing and therefore reduces the risk of an underground blowout.

Kicks that are improperly controlled or that exceed the kick tolerance in a drilling well can readily cause an underground blowout. The loss of hydrostatic pressure due to low-density kick-fluids displacing the drilling fluid can cause wellbore pressure at the casing shoe to increase after shut in until the fracture pressure is reached. The loss of mud at the fracture then allows additional feed-in from the kicking formation, and if not controlled, the conditions become worse until a continuous underground flow of formation fluids from the kick zone to the fracture results.

The original cause of the kick may be any of the typical causes: inadequate mud weight, abnormal formation pressures, not keeping the hole full, lost circulation, swabbing on trips, or flow after cementing. Any of the common complications in well control, such as uncontrolled gas migration, casing wear, pipe being off bottom, excessive kick size, or unidentified lost returns, may result in loss of well control leading to an underground blowout. Attempts to apply the “low choke pressure” method to high productivity wells have nearly always resulted in the underground blowout conditions that the method was supposedly going to prevent.

Underground blowouts can also occur in producing wells. This may result from loss of well control during workover or completion operations that leads to or results from a casing failure. It may also be a worst case result of a sustained casing pressure problem. These problems are caused by tubing and casing

leaks, wellhead leaks, packer leaks, and loss of annular cement seals. If the leak path becomes large enough and exposures weak formations or casing to excessive pressures, a continuous underground flow can result.

Control Methods

The general response to an apparent underground blowout seems to be a trial and error approach. Both diagnosis and solutions may be conducted in this manner. Control operations frequently start by trying to cure what is perceived to be the most likely problem and only revert to attempting to define the real problem after the first trial solutions fail. Control methods that are commonly attempted include:

1. pumping lost circulation material (LCM), gunk or cement to the loss zone in an attempt to regain conventional control,
2. bullheading kill fluids into the loss and/or producing zones,
3. a dynamic kill using frictional pressure loss and fluid density to increase wellbore pressure opposite the producing zone,
4. a weighted slug below the loss zone to overbalance the producing zone,
5. a “sandwich kill” that bullheads kill fluid from both above and below the loss zone,
6. a barite pill or cement plug to isolate the producing zone from the loss zone, and
7. a bridge plug set to isolate the producing zone from the loss zone, or more commonly just to provide a subsurface closure while surface equipment is changed or pipe is run in the well.

Successful application of any of these methods usually requires an implementation strategy that includes:

1. knowledge of the location, pressure, and flow characteristics of the entry and exit zones and the flow path,
2. definition of a kill approach and sequence that fits the diagnosed situation and the ultimate objective,
3. design of fluid constituents, densities, volumes, placement, and rates required for the intended approach,
4. acquisition of the necessary people, equipment, materials, fluids, and instrumentation to implement the design,
5. a plan for conducting the operation with predicted outcomes, usually pressures, to allow monitoring whether it is succeeding,
6. an agreed upon basis for stopping the planned operation, analyzing it, and defining an alternate approach if the plan is not progressing as predicted,
7. a method for confirming that progress landmarks are achieved before continuing to the next step, and
8. a method for finally confirming that the ultimate objective, usually permanent isolation of the producing zone from potential loss zones, has been achieved before considering the operation complete.

It should be evident from this list that engineering analysis and design; operational organization, implementation, and controls; and the coordination between operations and engineering are all important to achieving success.

Status in Industry Training Courses

The ability to prevent blowouts is widely recognized as a critically important element of any drilling operation. Therefore, well control training is used to give rig site personnel the practical and theoretical knowledge needed to develop this ability. This training is generally focused on “routine” well control issues such as prevention, detection, shut-in procedures, and conventional well control methods. However, training is also needed for the non-routine circumstances that lead to or result from an underground blowout. As described in the previous section, more complex engineering, operations, and organizational abilities are required under these circumstances.

Despite the need for training in these areas, there is generally a lack of coverage of underground blowouts in conventional industry well control training. This difficult and complex subject usually accounts for less than 5% of the time or material covered in a routine well control course. Prevention is closely related to properly implementing conventional well control procedures. However, some training may unintentionally increase the likelihood of underground blowouts if the limitations of the special procedures taught are not understood. The basis for more effective training is constrained by the shortcomings in our knowledge of good methods for the prevention, identification, diagnosis, control, and verification of control of underground blowouts.

Some well control manuals and references, such as Murchison², Abel³, Grace⁵, and Kelly, Bourgoyne, and Holden⁴, provide guidelines or flowcharts for a few specific situations or approaches to control underground blowouts. Wessel and Tarr⁶ describe a more general approach for assessing the risk of underground blowouts and planning a dynamic kill response. They also indicate that Mobil had developed internal computer programs for design of dynamic kills and training to support its use, as well for identification of underground blowouts. Others, notably Grace,^{5,7} have described diagnostic methods and kill methods as applied in the field. Petersen⁸ describes use of a computer simulator for design of kills specifically for underground blowouts. At least one operator has attempted to write general guidelines for diagnosing and controlling an underground blowout, but on an overall basis, no systematic method for addressing the problem of underground blowouts currently exists.

Actual case histories can provide a practical, if not necessarily comprehensive, basis for demonstrating why conventional well control practices are important in preventing underground blowouts, how well control situations can become underground blowouts, and what the critical “turning point” decisions are for preventing or controlling an underground blowout. The case histories described in the following section were chosen to provide these kinds of insights. They demonstrate clearly how seemingly arbitrary and mundane prevention and monitoring practices taught in conventional training are critical for avoiding underground blowouts, particularly in deep, high-pressure wells. They provide evidence for understanding how apparently routine operations evolved to become underground blowouts. Finally, they provide a factual basis for evaluating key decisions that must be made during well control and understanding how and why engineered solutions were ultimately successful.

UNDERGROUND BLOWOUT CASE HISTORIES

Case histories from industry supporters and the authors provide the knowledge base that was used to create the training modules. Analysis of these histories provides key learnings to be communicated in the modules.

Case histories were selected as the means for developing a reliable, factual basis for improved training in handling underground blowouts in the original plan for this project¹. Multiple case histories have been provided by industry sources, and several have been selected as appropriate for this purpose. In addition, case histories are also described in some existing well control literature as by Grace^{5,7}, Murchison², Bourgoyne¹⁵, Moore¹⁶, and Abel³. In general, the examples in literature provide enough information to make and support a key point, but not to develop a full training module. The following four case histories are the basis for the modules described herein. Two additional well-documented case histories are also introduced. These have been reviewed and are potential candidates for additional training modules.

An Underground Flow Offshore Texas

The “Case History of An Underground Flow Offshore Texas⁹” was previously documented in an interim report¹⁰ and an SPE paper¹¹. The case history describes the operator’s experience drilling two moderately deep, highly overpressured, gas wells that were the fifth and sixth wells on a platform offshore Texas. Figure 2 is a wellbore diagram showing the conditions that existed when the underground flow began and important features of the well design.

The underground flow in the fifth well was caused by either or both of lost returns while running and cementing or flow after cementing a production liner opposite a high pressure gas zone. The flow was identified after releasing from the liner top and reversing out the cement. An attempt to perform an off bottom, circulating kill resulted in increased surface pressures. Bullheading and a liner top squeeze eventually isolated but did not stop the underground flow behind the liner. Several months later, evidence of an underground flow was detected while drilling an adjacent well. The clue was that increasingly higher pressure kicks were taken on two attempts to drill through a previously normally pressured sand. Diagnosis with cased hole logs then confirmed the existence of an underground flow behind pipe in the fifth well. A dynamic kill was designed and was followed by several remedial cementing efforts that were eventually successful in isolating the producing zone from shallower, weaker formations. The success of these efforts was verified with temperature, noise, and cement bond logs.

Module 1 was developed as an interactive group training exercise. The Petroleum Engineering and Industrial Engineering departments at LSU have subsequently used this case history as the basis for Module 2, a programmed learning exercise. These two modules are described in more detail in Chapter 6. The modules are included as Appendices A and B.

Additional details of the actual case history are included in the description of Module 1 and in the training modules themselves.

Key Learnings

Key learnings that are evident from that description of the case history are:

1. Kick detection while tripping in the hole requires that the mud volume displaced from the well be monitored with a trip tank.
2. Kick detection during lost returns, as occurred while running and cementing the liner, requires that the hole be kept full and that the volume to fill the hole be recorded.
3. Avoiding lost returns while running and cementing tight clearance liners requires special design of equipment, fluids, trip speeds, and circulating rates to minimize surge and equivalent circulating density (ECD) effects.
4. Even small kicks can result in major well control problems if improperly handled.
5. Control of an underground blowout with the drill string above the exit point is generally not feasible. Special procedures are required to evaluate pressure behavior below the end of the drill string.
6. Bullheading kick fluids and cement back into open hole formations from above the exit point generally will isolate the upper portion of the well from the underground blowout but will not stop the underground blowout unless natural bridging has occurred in the open hole..
7. Possible underground flows outside pipe require diagnosis by methods other than pressure inside the pipe. Examples are temperature logs, noise logs, TDT logs, Cement bond logs, and surface pressures on outer annuli.
8. Even severe, long-term loss of well control can be corrected with carefully engineered, implemented, and monitored procedures.

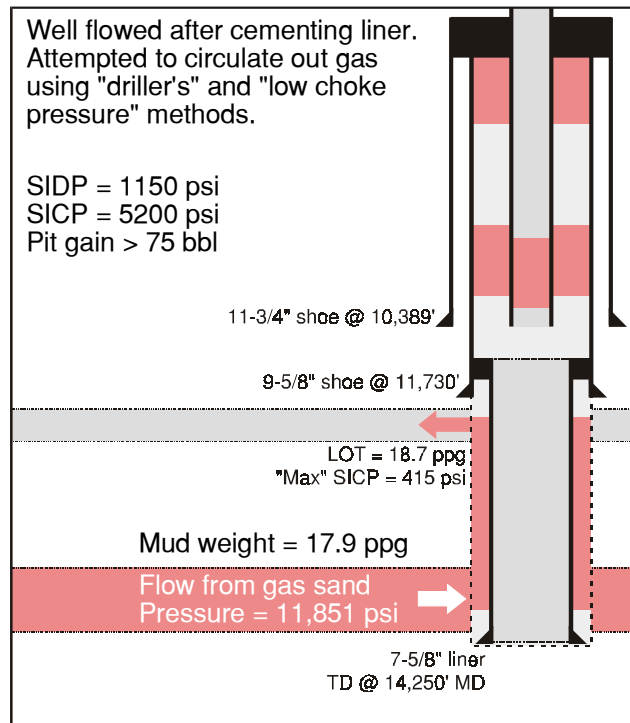


Figure 2 - Wellbore During Underground Flow Offshore Texas

Underground Blowout in Deep Gas Well

An "Underground Blowout in Deep Gas Well^{13,14}" is another data set that was described briefly as a "deep underground flow" in previous interim reports^{10,12}. The underground blowout occurred during a trip in the hole in a deep gas well. A wellbore diagram of the well at the time it was shut in is shown in Figure 3. The following is a chronological description of the event.

A deep, offshore gas well had been drilled to a total depth below 22,000 feet measured depth and 21,000 feet true vertical depth. The objective sand had been reached and found to be gas productive. Several conventional cores had been taken and recovered. A 12.5 lb/gal mud was being used which provided an overbalance of approximately 550 psi. A 9.625 inch liner had been set and cemented just below 13300 feet and tied back to the surface with 10.75 inch pipe. The leak off test at the liner shoe was equivalent to 13.7 lb/gal.

A 60 foot long core of the objective sand was tripped out of the hole. Previous trips had caused no problems, and the overbalance should have provided more than adequate trip margin. However, careful monitoring of the trip tank indicated that the hole had taken 2.5 barrels less than expected. This was not considered to be a problem because it was a relatively small error for such a long trip and the previous successful trips had experienced even larger discrepancies. There was no flow from the well after the trip out, and it was considered successful.

A new bit was picked up and the trip in the hole began uneventfully. The trip was interrupted at the 9.625 inch casing shoe to slip and cut the drill line. There was still no indication of flow from the well. The trip was then continued to 18,400 feet, where pit level measurements indicated a gain was occurring. The well was checked for flow and observed to be “flowing slightly.” This was concluded to be thermal expansion of mud, and the trip was continued.

Tripping continued to about 19,300 feet, but the pit level had continued to increase in excess of pipe displacement. The trip was again interrupted, and the well was shut-in. The shut in drill pipe pressure was 0 psig, but the shut-in casing pressure was 100 psig. The cause of the casing pressure was concluded by rig personnel to be a “U-tube effect from out of balance mud.” Consequently, the trip was again continued.

In reality, a pit gain of at least 55 barrels had been recorded over the previous 1.5 hours. A quick calculation shows that this size gas influx would cause about 450 to 600 psi loss of hydrostatic head, depending on where it was in the annulus. The actual total pit gain was probably larger given that the initial pit gain had occurred much earlier, but earlier pit volume records were not available. A larger gain could easily cause the 650 psi loss of hydrostatic head necessary to cause the 100 psig shut in casing pressure. If so, the well was underbalanced when the trip was continued, and influx from the formation was almost certainly occurring during connections.

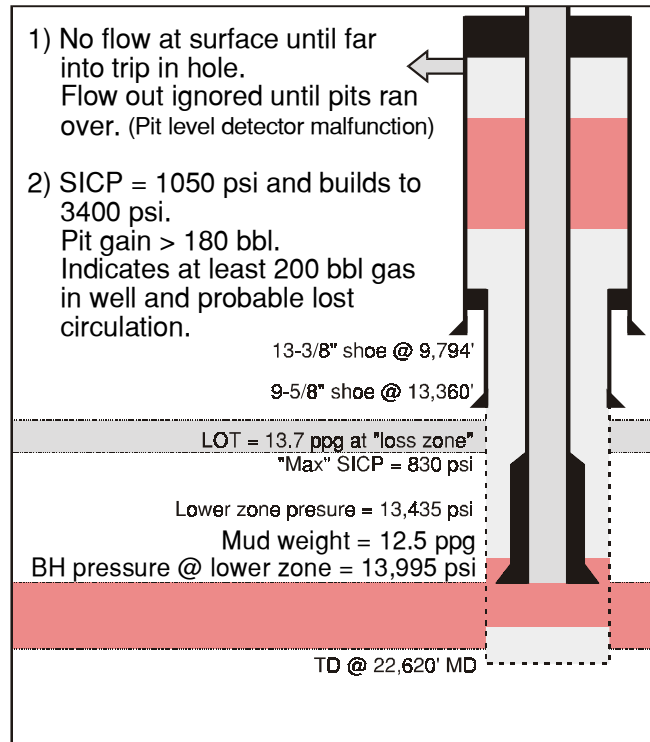


Figure 3 – Wellbore Diagram Showing Conditions when Shut In on “Underground Blowout in Deep Gas Well”

After tripping to about 19,750 feet, the rig crew concluded that they should circulate to get the mud back in balance. Although the continuing pit level gain showed that the well was still flowing at this point, it was not shut-in or circulated on the choke. When circulation began the total pit gain was at least 73 barrels more than calculated pipe displacement. At this point, the shut in casing pressure would probably have been about 300 psig. If the well had been shut in, it would have been obvious that mud imbalance was not the problem. A shut in casing pressure of at least 830 psig could be contained without losing returns based on the leak off test. Therefore, it is likely that the well could have been killed conventionally at this time.

Circulation continued for about 30 minutes more. During this time, the pit level indicator being observed by the operator's representative malfunctioned and showed no gain. The mud logging crew observed that the pit gain was continuing but did not advise the operator's representative. Afterwards, a review concluded that a "lack of clear communication" contributed to the "improper" actions taken by the rig crew. Another 108 barrels of gain were taken before the pits ran over. Circulation continued another 30 minutes before the rig personnel concluded that the well was really flowing and the Blowout Preventers were closed. While the total pit gain when the well was finally shut-in is unknown, it was substantially more than the 181 barrels indicated by the mud logging records at the time the pits overflowed. The shut in casing pressure was 1150 psig. If all or most of the influx was below the 9.625-inch casing shoe, this pressure was sufficient to result in lost returns which would initiate an underground blowout.

The drill string was almost 3000 feet from the bottom of the borehole. Stripping was begun in order to get the bit closer to TD to allow for a conventional well kill to be attempted. After stripping 8 stands into the hole, the shut-in casing pressure had reached 3400 psig. The cause for this increase is not certain, but loss of mud to the fracture zone, gas migration, and failure to bleed off pipe displacement would all cause shut in pressure to increase. The upper stripper began leaking at this time, allowing an additional 40-barrel gain. After shutting in to repair the stripper, the shut in casing pressure was 4100 psig. Given these excessive pressures, an underground blowout was almost certainly in progress. An additional complication was that the drillstring became stuck during the stripper repair with the bit still more than 2000 feet above TD.

The seriousness of the situation was finally obvious. It was clear that conventional control methods were unlikely to succeed, and preparations were begun to perform an off-bottom kill. Engineering calculations indicated that a dynamic kill could be achieved by pumping several thousand barrels of 13.5-lb/gal mud through the drillstring and the upper portion of the open hole at a rate of about 17 bbl/min. This would require that additional mud, pumps, personnel, and other resources be delivered to the rig. In the meantime, the risk of a surface blowout could be reduced by minimizing surface pressures.

Surface pressures were reduced by intermittently bullheading mud into the annulus and pumping mud into the drillstring to keep both at least partially filled with mud. Gas that migrated to the top of the annulus was bled off and replaced with mud during periods when bullheading was interrupted. Noise logs were run in the drillpipe to confirm flow in the annulus was occurring. The outer casing annulus pressures were monitored for changes to verify that conditions were not becoming worse. After five days of preparation and rig up, the kill operation was ready to begin, and shut in casing pressure had been reduced to 1055 psig.

The final kill plan was to pump 4000 barrels of 13.5-lb/gal water based mud down the drillstring at a rate of 17 bbl/min and a pressure of at least 6500 psig. The mud would exit the bit and return up the annulus with the gas flow to the loss zone just below the 9.625-inch casing shoe. This rate and density was calculated to raise the pressure at the bit enough to prevent further gas influx. Then 1000 barrels of 15.5

lb/gal mud would be pumped and left to fill the annulus between the bit and the shoe. This would insure a hydrostatic kill of the well even if gas were left in the well below the bit.

Three workboats were tied into the rig mud pits to provide a total of 5600 barrels of 13.5-lb/gal mud. Another workboat held 2000 barrels of 15.5-lb/gal mud. Three turbine-driven pump skids provided about 4000 hydraulic horsepower for the large volume, high pressure pumping job. Engineers had not only designed the procedure, but had also predicted the expected pressure versus rate response throughout the job and provided criteria for determining whether the job was succeeding and should be continued.

The kill operation began by pumping the 13.5-lb/gal mud down the drillstring at 3 bbl/min and staging up to 17 bbl/min to allow verification that hydraulic predictions were correct. Initial pump pressure at 17 bbl/min was 6000 psig. 13.5-lb/gal mud was also pumped continuously down the annulus at ½ bbl/min during the entire procedure to minimize gas migration in the annulus. As mud began to fill the open hole annulus, this pressure increased to 6900 psig. A steady state condition of 6800 psig at 16.3 bbl/min was achieved after pumping about 700 barrels. This combination indicated that a dynamic kill had been achieved. Circulation continued for another 1000 barrels to help remove some of the remaining gas from the open hole annulus. Then the planned 1000 barrels of 15.5 lb/gal was pumped at a final rate and pressure of 14 bpm and 5350 psig. Success of the kill operation was confirmed by running noise and temperature logs to verify that downhole flow had ceased.

Analysis of Underground Blowout and Key Learnings

There are several important learnings that can be drawn from this experience. These relate to the causes of kicks, detection of kicks, reaction to unconfirmed kick indicators, and control of severe well control problems.

The actual cause of the initial gas influx into this well is not known. The operator concluded that one or both of the following could have caused the initial kick that proved so hard to detect conclusively.

1. 1. Swabbing on the trip out of the hole. Although the indicated 2.5 barrels swabbed was less than on some other trips, even this small volume could have caused the well to go underbalanced when it migrated, or was circulated, to within 1000 feet of the surface. A significant increase in trip gas measured on the last previous trip is indicative that some minor swabbing may have occurred on it as well.
2. 2. A 60-foot core was cut prior to the trip. The gas volume in the volume of formation drilled would have been about 0.6 barrel at bottom hole conditions. Even this tiny volume could theoretically cause the well to go underbalanced if it were brought to within 200 feet of the surface as a single bubble. Bottoms up had not been circulated prior to the trip out, and a portion of the formation gas would have been present in the core. Consequently, it is possible that all of the “drilled gas” remained in the well during the trip, and migrated slowly towards the surface.

The key learning is:

1. A small volume of gas influx can expand enough to displace mud from the well and cause it to become underbalanced, especially in a deep well.

Swabbed in kicks, or other kicks taken during a temporary underbalance, can be difficult to detect. In this case, the “kick” was almost certainly taken during the trip out of the hole as explained above. It was only detected after tripping over 18,000 feet back in the hole.

The key learnings are:

1. A small volume gas kick can go undetected while migrating until its volume expands enough to unload enough mud to initiate flow or to cause a significant trip tank or pit level change.
2. The large overbalance in this case meant that the gas influx had to expand to about 55 barrels to cause the well to go underbalanced. Therefore, flow checks were negative or inconclusive even after easily identified pit level indications.
3. A negative flow check is not proof that no kick was taken in a well, only that there is no influx occurring currently. This is especially important to remember during trips.

Reaction to an unconfirmed indication of a kick is important. In this case, tripping was continued, and then circulation initiated without careful monitoring or evaluation of the flow, pit level, and pressure indications that were observed. The initial indication of a possible kick was apparently a steady pit gain in excess of what was expected due to pipe displacement while tripping in the hole. The minor flow noted at 18,400 feet confirmed the possibility that a kick had been taken.

The increasingly strong indicators that a kick had been taken continued to be discounted until after a very large influx had occurred. The pit level increased rapidly after enough mud was displaced to cause the well to be underbalanced. The pit level increased even more rapidly when circulating because the gas was being brought to the surface and expanding even faster in addition to the new influx being taken from the formation.

The key learnings are:

1. Questionable kick indications require a cautious reaction. The primary concerns should be detecting whether a kick has occurred and maintaining the ability to initiate an effective well control procedure.
2. Alternative causes for questionable kick indications should be evaluated before being accepted. For example, an imbalance in mud densities would not cause a continuing flow. The flow, or SICP, would decrease as mud was bled off of the annulus and the fluid level in the drillstring dropped.
3. The slow increase in pit level and insignificant flow that occurs while gas is migrating will increase rapidly when the well goes underbalanced.
4. Circulation brings the gas up faster, increases the rate of pit level increase, and decreases reaction time. Circulating bottoms up to eliminate unbalanced mud or to check for gas should be done only while carefully monitoring pit level. The crew must be prepared to shut the well in if additional pit gain is observed.
5. If the well is not shut in when the well becomes underbalanced, additional kick volume will begin feeding in rapidly. The well must then be shut in immediately. Postponing shut-in until the pit gain is large can cause excessive shut in pressure, lost returns, and risk of an underground blowout. Consequently, circulating the well on choke is inherently safer than routine circulation if a kick is suspected because it minimizes the risk of taking a larger kick and losing control.

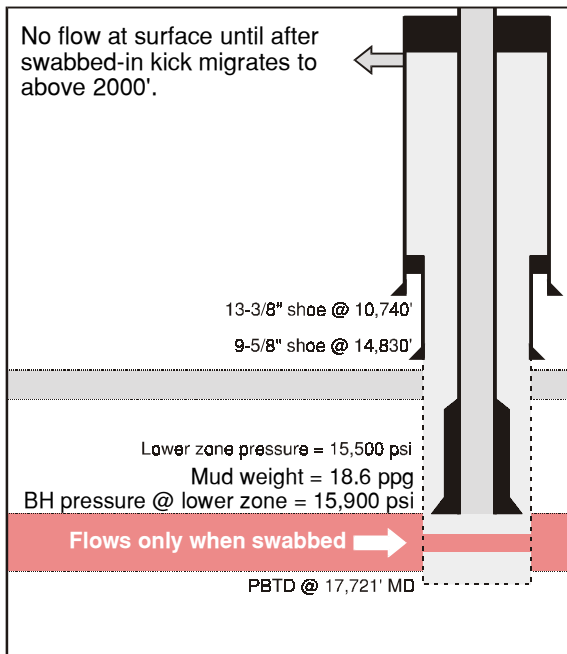


Figure 4 - Wellbore Diagram for "Near Miss due to Swabbed-in Kick"

The delay in reacting properly to the initial gas kick and the subsequent large kick caused a major underground blowout. A gas formation with 120 feet of 40-millidarcy sand and a 13,400-psig reservoir pressure was flowing uncontrolled into another permeable zone almost 8000 feet shallower. An effective kill procedure required density, volume, and rate high enough to overcome this high rate underground flow and ultimately to regain hydrostatic control despite having over 2000 feet of open hole below the bit.

The key learning is:

1. Well control for underground blowouts and off-bottom conditions requires special procedures not typically addressed in conventional training. Nevertheless, even a severe loss of control can be corrected with a properly designed and executed operation.

This case provides logical confirmation for the learning in Module 3. The module is described in Chapter 6 and included as Appendices C.

Near Miss Due to Small Swabbed Kick

Near misses can also provide a basis for case history-based learning exercises. This case history is based on one of the authors' personal experience with a small kick that was apparently swabbed-in during a trip out of a deep gas well. This kick did not result in an underground blowout. However, the well had previously experienced lost returns, and underground blowouts had been experienced in previous wells in the area. Consequently, although it was successfully controlled, it is considered to have been a near miss.

The significance of this case is that it developed in a similar manner to the previous case, but the cause of the kick is somewhat better documented and understood. The kick was identified just as a production liner was beginning to be run, and the kick can be concluded to have been caused by swabbing on the trip out of the hole. A summary of the experience is described in the following paragraphs. Figure 4 is a wellbore sketch indicating the general configuration of this well during the trip out of the hole.

The well had been drilled to the objective TD below 18,000 feet. After correcting lost returns experienced at TD, it was logged, and a cement plug was set below 17,500 feet to isolate the lost circulation zone near TD from shallower, potentially productive intervals in the open hole. The cement plug was dressed off, the well was circulated clean with 18.5-lb/gal mud, and a trip out was made to run a production liner. Fill-up volumes were monitored throughout the trip. The trip was judged to be routine except for two factors. First, the trip was made somewhat faster than most previous trips. Second, a four-barrel "gain" had been noted while laying down drill collars. At the time, the operator believed that this "gain" was caused by

water from washing the floor spilling into the trip tank. The well was checked and found to not be flowing.

Preparations were then made to run the 7-inch production liner, and there was no additional pit gain during this time. However, excess mud displacement from the well was noted almost immediately while running the liner. Liner running operations were halted temporarily, and flow checks made on two occasions while running the first few joints of liner into the well. No flow was observed, and running continued. "Auto-fill" float equipment was being used to minimize surge pressures and the risk of lost returns. Incomplete filling of the pipe was thought to be a possible cause of the fill-up volume discrepancies. Flow checks continued and flow was eventually confirmed while the liner was still being run. The remainder of the liner and 15 stands of drillpipe were run with the well flowing slightly. Having all of the liner in the hole and drillpipe opposite the Blowout Preventers, allowed the well to be closed in a condition that would allow stripping into the hole. Shut-in drillpipe and casing pressures were equal at just above 900 psig. Obviously at this point in time, a large kick existed below the 7-inch liner that was sufficient to cause these shut-in pressures. However, the initial kick must have been swabbed in much earlier. The well only began to flow, allowing the large kick, after the initial kick fluids migrated to the upper part of the well. It is likely that the length occupied by initial kick fluids probably also increased as the liner was run into the section of the well where they were present.

The decision was made to strip the liner in the hole to be able to circulate closer to the likely kick zones. The float equipment was activated so that it would prevent flow up the drillpipe and stripping commenced. Ten stands of drillpipe were stripped before the annular preventer element failed. The well was shut in on the pipe rams and the element replaced. Stripping then continued to about 17,000 feet, where the liner became stuck. The well was killed conventionally at that depth and the liner was cemented successfully.

A maximum pressure of about 1400 psig was encountered during stripping. Gas and salt water cut mud were circulated out during the kill but in smaller volumes than expected. A large amount of mud had been lost during the stripping operations, and apparently, this was equivalent to bullheading a significant fraction of the kick fluids back into the formations in the open hole.

Analysis and Key Learnings from Swabbed Kick

The precise cause of this kick has never been conclusively determined. Most likely, it resulted from a small, swabbed-in kick at the beginning of the trip. This conclusion is based on the trip being faster than previous trips, the occurrence of balling and swabbing on previous trips, the "gain" observed while laying down drill collars, and the common occurrence of incorrect hole fill-ups observed on the first few stands pulled. Although this last possibility is not documented for this trip, it was experienced on earlier trips. It has been simulated and demonstrated as a feasible explanation for the actual sequence of events.

The seemingly late reaction to the kick indicators was still quick enough to prevent the excessive pit gain and excessive shut in pressures experienced in the previous case history. The rig personnel's acknowledgement that a kick had occurred and readiness to initiate stripping, which they had been trained for during pre-spud preparations, before flow became excessive were important their success. The low formation permeability and combination of water and gas production made their challenge easier.

This case is the basis for Module 3 described in Chapter 6 and included in Appendix C. The key learnings are similar to the previous case history:

1. A very small volume of gas influx can go undetected while migrating until its volume expands enough to unload enough mud to cause a significant pit gain or to initiate flow.
2. Stripping in the hole allowed relatively conventional control of an off bottom kick taken during a trip.

Kick Taken while Drilling with Low Kick Tolerance

A well control situation experienced by one of the authors provides another useful case history. There was no direct evidence that an underground blowout occurred during control of this kick, but significant lost returns and relatively high surface pressures were encountered during control operations, which indicated that some underground flow was likely. Control was regained quickly so that an extensive underground blowout was avoided.

The subject well was being drilled with a 16.2-lb/gal mud at a depth below 11,600 feet. The predicted pore pressure gradient in this section was equivalent to a 15.2-lb/gal mud and was based on a formation test in an offset well. The mud weight had been increased to 16.2 lb/gal based on mud gas trends and an interpretation of formation resistivity data obtained using a Measurements-While-Drilling (MWD) tool. Intermediate casing was set at 9850 feet, and the shoe had been tested to an equivalent of 17 lb/gal. The blowout preventers had been tested to 10,000 psi.

A flow check was made after drilling 2 feet into a drilling break. The well was flowing and a Blowout Preventer was closed. The initial shut-in pressures were 375 psi on the drillpipe and 260 psi on the casing,

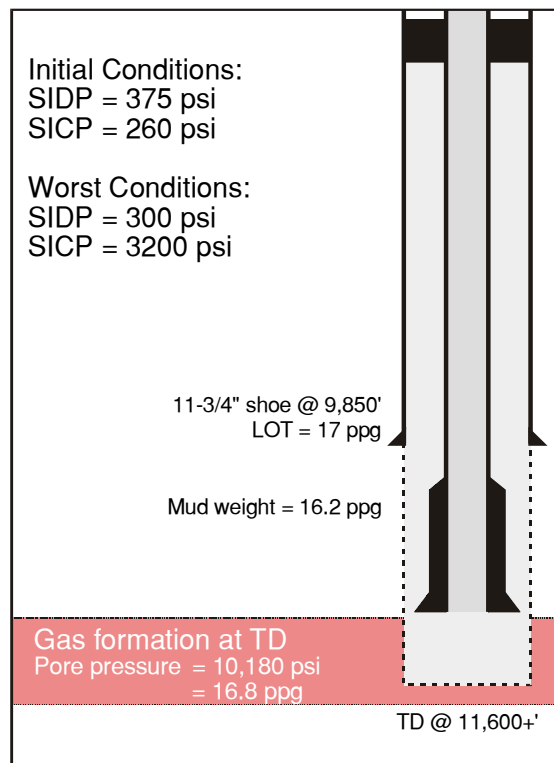


Figure 5 - Wellbore Diagram for Gas Kick Taken with Low Kick Tolerance

(see Figure 5). The pit gain was not recorded, but all indications are that it was small. The maximum shut-in casing pressure before formation fracture was calculated to be about 540 psi if the casing annulus was filled with mud. Therefore, formation breakdown was not expected when the well was initially shut-in. However, the drillpipe pressure being higher than the casing was cause for concern that breakdown had occurred. Both drillpipe and casing pressures increased over the next few minutes, but a little more than 10 minutes after shut-in, the drillpipe pressure began to drop while the casing pressure continued to rise. The well was checked for trapped pressure by bleeding small volumes of mud from the annulus, but casing pressures continued to rise slowly.

Kill weight mud having a density of 16.8 lb/gal was mixed over the next 6 hours. After weighting up the mud, the shut-in drillpipe pressure was 300 psi and the casing pressure was about 3200 psi. At this point in time, mud was almost certainly being lost due to fracturing at the casing shoe resulting in additional kick volume being taken. The casing pressure implies that roughly 4000 feet of the well was filled with gas. This verifies that additional gas influx had occurred after the initial kick and that

some underground flow was occurring. Given that severe mud loss was occurring, the original plan to control the well using the weight and wait method was abandoned.

A bullhead “sandwich kill” was implemented using the 16.8 lb/gal mud to displace most of the gas kick into formations in the open hole and reduce surface pressures. A total of 960 barrels was bullheaded down the casing at 3 bbl/min to overdisplace the casing annulus down to the casing shoe. Simultaneously, 363 barrels were bullheaded down the drillpipe at 1.7 bbl/min to displace the drillpipe and the open hole annulus up to the casing shoe. The resultant shut-in pressures were 115 psi on the drillpipe and 520 psi on the casing. The shut-in pressures were monitored for an hour with the drillpipe pressure constant and the casing pressure increasing only 20 psi. Consequently, it was concluded that the inflow had been stopped and that relatively little gas remained in the well.

Over the next 14 hours, a volumetric kill procedure was used during which 60 barrels of mud were lubricated into the casing annulus in 5 barrel increments. Gas was removed from the well by periodically bleeding to decrease the casing pressure by 50 psi, which is an amount equal to the hydrostatic pressure of 5 barrel increments of mud. However at the end of this operation, the shut-in casing pressure was 580 psi and the drill pipe pressure 120 psi, indicating that little progress was made. Mud was then pumped down the drillpipe at 0.5 bbl/min in 5 barrel increments and casing pressure bled off in 50 psi increments to lubricate gas from the annulus. After lubricating about 100 barrels into the drillpipe, casing pressure had been reduced and stabilized at about 250 psi.

The well was then circulated for a conventional kill at a rate of 2 bbl/min. This rate was chosen to minimize friction losses in the annulus and therefore minimize the risk of lost returns. The maximum casing pressure observed was 480 psi. After circulating a total of about 1700 barrels or about 1.4 times the volume of the well, the drillpipe circulating pressure was 315 psi and the choke pressure was 60 psi. The well was then shut-in. After trapped pressure was bled off, the well was determined to be dead. It was opened, and the flow check indicated that it had been successfully killed.

This case history is the basis for Module 4 described in Chapter 6 and included as Appendix D.

Key Learnings

The key learnings from this case history are:

1. The threat of a kick becoming an underground blowout is real, even when well control conditions seem favorable. The apparently adequate kick tolerance and overbalance, use of MWD and mud loggers for pore pressure determination, and conservative kick detection precautions to minimize kick volume did not prevent taking a kick that could not be controlled using routine methods. Unexpected geological conditions can cause well control problems even when best drilling practices are being used.
2. As in other cases, a shut-in well is not necessarily a controlled well.
3. Adequate resources at or near the rig site, such as pump rate capability, surface mud volume, mud weight up capabilities, and knowledgeable on-board and support personnel, allow relatively rapid response to a threatening well control situation. A rapid, appropriate response can minimize the surface pressures experienced.
4. A “sandwich kill” can be a relatively quick and effective means of reducing surface pressures and regaining control of a kick that has resulted in simultaneous influx and lost returns. (Note: regaining control essentially depends on achieving a dynamic kill of the open hole

interval. This is most likely to be successful when the formation productivity is low and when a portion of the kick fluid is formation water.)

South Texas Blowout

A South Texas Blowout is another well control incident that was discussed in a previous interim report. A full training module was not developed for this case, but it could provide additional material for discussion in a well control course. This incident began with lost returns while drilling with oil-based mud in an overpressured gas reservoir. A large gas kick was taken while trying to cure the lost returns. The volume of the kick and the presence of a lost circulation zone apparently contributed to the development of underground flow. Eventually, the ineffective attempt to stop lost circulation resulted in excessive pressure on the drillpipe, which ultimately resulted in blowouts up both the drillstring and the casing-drillpipe annulus.

Key Learnings

Key learnings from analysis conducted to date on the “South Texas Blowout” are that:

1. A large kick size resulted from not keeping the annulus full and not shutting in immediately when returns were achieved after severe losses.
2. A water-based cement slurry was more effective in sealing an apparent loss zone than lost circulation material in oil-based mud.
3. Failure to control an underground blowout can lead to excessive pressures and consequently to surface equipment failures that result in a surface blowout.

Shallow Gas Blowout Due to Flow after Cementing Surface Casing

A new and relatively well-documented case history has also been acquired for a shallow gas blowout that occurred shortly after cementing surface casing on a well in the Gulf of Mexico in 1997. Although not developed into a training module, this example is useful for class discussion of a problem that has occurred a number of times in the past. This is another case where lost returns had been experienced prior to the cement job, but there was no consistent effort to ensure that the annulus was kept full during and after cementing. Therefore the cause of the flow cannot be exclusively attributed to either the lost returns or the classical flow after cementing phenomenon. Nevertheless, this case provides another example of the importance of monitoring lost returns and taking appropriate precautions before nipping down the diverter head and diverter system.

Key Learnings

Key learnings from analysis conducted to date on the “Shallow Gas Blowout” are that:

1. The annulus must be kept full to maintain an overbalance on the permeable formations in the open hole and prevent a kick from being taken.
2. If the annulus will not support a full column of mud due to the lost returns, it should be filled with water and the volume used should be measured. This minimizes the loss of overbalance

and allows rapid identification of any kicks. This blowout could have been diverted if the kick had been identified before the diverter was disconnected.

3. A gas blowout from a sand within a long interval that also contains water sands will usually result in water-bearing formations also contributing to the blowout.

TRAINING MODULE DESIGNS

Training can be effectively delivered in many different forms. Interactive exercises and training simulations are two forms that have proven successful when using case histories for well control training

Task 10 of the current research program was the development of training modules based on the simulation and analysis of underground blowout case histories. The training methods used to develop the modules for this project have taken two general forms: interactive case history reviews and simulations matching or emulating actual case history conditions.

Interactive Case History Reviews

A prototype training module was designed to apply a philosophy of learning through practical problem solving on real situations. The philosophy is to emulate hands-on learning with what we call “minds-on” learning. This style of learning is more than just a review of the facts of the case history. Specifically it requires the training participants to make their own decisions about how to handle each phase of an actual underground blowout experience, consider the possible results qualitatively or quantitatively, and then compare their expectations to the actual results achieved. Conceptually, each participant is expected to act as if he or she was part of the drilling organization handling the underground blowout at the time it occurred. The programmed learning module is also based on this same philosophy.

The decision points in the actual well control experience provide the practical problems to be solved in the training module. These decisions that control every well control incident are organized by the phases of the well control process. These phases are essentially the sequence of major events that can occur in a well control incident. This sequence of phases and the related decisions then provides a logical organization for explaining the sequence of events in a well control incident. The sequence of phases used for the training module is:

1. Planning and preparation--actions and decisions determining well design, safety factors, and contingencies
2. Prevention--actions that identify and decisions that correct potential causes of kicks
3. Detection--actions leading to detection and decision that a kick is indeed occurring
4. Reaction--decision whether and how to react to an apparent kick
5. Control--decision on what control method to use, how to determine if it is working, and when to change it
6. Recovery--decisions leading to recovery of control (correcting the UGBO) if it was lost
7. Confirmation--decisions on whether and how to confirm that control was regained

This sequence generally coincides with the chronological sequence of events. Consequently, it provides an easily followed path through the decisions that caused operations to evolve from routine activities (with prevention being the primary focus) to an underground blowout. For the cases we have now, this sequence also provides the path back through the decisions and recovery efforts that are eventually successful in returning the well to routine operations. By applying the subsection learning sequence described below to these key decisions, we give the participant the chance to analyze and make the decisions for themselves and to evaluate and learn from their decisions.

The process of participants making a decision and then analyzing it conceptually in the context of the decision implemented in the actual well creates a subsection of the training module. These subsections can be thought of as “minds-on” interactive learning exercises. A typical sequence of events in a group exercise is:

1. A point in the well control process is reached where an operational decision must be made. Example decisions include which kill method to use, whether to continue a method that is not performing as expected, or whether the well is safe to return to routine operations.
2. The status of the well is described to the extent that it is known.
3. The participants “brainstorm” potential actions to regain or maintain control of the well.
4. The participants and leader hypothesize the probable outcome of those actions, including calculations where appropriate.
5. The participants then decide what action they would take.
6. The actual action taken is described, and if different from the proposed actions, its probable outcome is hypothesized.
7. The results that actually occurred are reviewed and compared to our hypotheses. Our “mistakes” are discussed to identify probable causes and potential corrections. Implications regarding the probable success or failure of the alternative actions that were identified by the participants are discussed.
8. Our “experience” is reviewed. In particular, factors that contributed to success or failure or that could have corrected our course of actions are identified, so that they become part of our common knowledge for addressing subsequent decisions.
9. Then the process is repeated at each important new decision point until the well is successfully returned to routine operations.

Each major decision in a well control incident can be addressed with the preceding sequence depending on its importance and the quality of the information relating to it in the case history. The sequence is applied to the key decisions or learnings resulting from a given case history. The sequence is used in a more abbreviated manner to address all of the documented decision points in a given case history. The discussion should emphasize cause and effect and the importance of effectively using available resources without requiring participants to analyze every decision.

One of the most critical decisions in every underground blowout experience is how to attempt to regain control and recover from the blowout. This decision would typically be one that is addressed using the subsection sequence. The analysis of whether the control methods identified during the brainstorming apply to the situation at hand can begin by using another conceptual model. The model defines the general steps involved in the “recovery” phase operations, which are:

1. Define and establish hydraulic path to zone of concern, if it does not already exist,
2. Stop influx,
3. Remove influx,

4. Regain hydrostatic control, and
5. Achieve zonal isolation.

These are very similar to the steps in conventional well control, but accomplishing them may be significantly more difficult.

The methods proposed by participants for regaining control can also be considered using the required elements of a successful implementation strategy described in the previous section. A method should be altered if:

1. it will not achieve a necessary step in the well control process,
2. the results cannot be predicted at least qualitatively,
3. the resources to implement it are unavailable,
4. if it cannot be controlled, or
5. if it precludes corrective action in the event it fails, it or rejected.

This kind of logic is also suggested by Grace⁵ and Wessel⁶. Considering and comparing the alternatives relative to these issues reinforces the need for the proposed solution to be developed using the effective cooperation between operational and engineering personnel. This cooperation is necessary for engineers to know what is operationally and logistically possible and what information is needed by operations to implement it. Likewise, it is necessary for operations to understand what is to be accomplished, why, and how to determine whether it is working or it is failing and needs to be stopped before making the situation worse.

The actual reasons for the success or failure of the methods used in the case history can then be provided in a logical sequence and context. Understanding these reasons in a practical context creates the factual key learnings within the module. They also provide a basis for validating or revising the expected results from the participants' proposed alternatives as well. Although having quantitative or conclusive predicted results for every possible alternative that participants may suggest is impractical, the group can make reasonable conclusions about the success of most alternatives. When this is not possible, the group can acknowledge that the other alternatives might be successful but require real engineering analysis or trial and error experimentation to know.

When a training module is completed, the participants should have drawn their own conclusions about:

1. the causes of the actual blowout,
2. the decisions made,
3. about more effective ways to avoid and control similar situations in the future, and
4. about the analysis and planning required to select and implement effective recovery procedures.

They should also have learned both the basic factual, technical requirements for successfully using the procedures discussed and some of the logical and conceptual requirements for addressing a new problem. Consequently, they should be better prepared for dealing with an impending or on-going underground blowout than if only conventional training had been provided.

Programmed Learning Exercises

The same logic used in the interactive learning exercise can be applied in an independent learning exercise. The user must go through the same process, but the discussion is with the pre-programmed software

rather than a group and a knowledgeable instructor. Therefore the program is set up to require the user to consider factors and alternatives that would typically be identified by the group. It also provides the feedback on the decisions made.

A sequence equivalent to that in a group exercise is used in a programmed learning module. The typical sequence followed in a programmed learning exercise is:

1. Ask a question, usually about what operation should be performed given existing conditions.
2. Offer possible alternatives.
3. Critique participant's selected alternative with feedback on why it is or is not appropriate.
4. Allow revised selection until an acceptable alternative is chosen.
5. Advise the actual action taken in field.
6. Ask likely outcome of that action.
7. Advise the real outcome to establish existing conditions for next decision point.
8. Go to next decision point.

This learning sequence involves much less creativity and interaction than the group learning exercise. Nevertheless, it provides a way to instruct an individual on the case history without requiring an instructor or other participants. When a training module is completed, the student should have learned:

1. the precautions necessary to avoid a similar problem,
2. the basic technical requirements for successfully using the procedures discussed,
3. and some of the logical and conceptual requirements for addressing a new problem.

Consequently, the student should be better prepared for dealing with an impending or on-going underground blowout than if only conventional training had been provided.

Case History-based Simulation Exercises

The original proposal¹ for this task envisioned that learning modules could also be built around simulations based on case histories. This approach allows focus on a specific situation or decision and allows the training participant to make unbiased decisions and to see the results. This can combine the "hands-on" advantages of conventional training simulations with the realism verified by comparing simulation results to the factual results in a case history. Simulations allow participants to monitor operations using simulated rig monitoring equipment and take actions on simulated rig equipment. Consequently, they provide practice in a more realistic context than interactive exercises using descriptions and graphics.

A training simulation of an entire well-control event leading to and correcting an underground blowout is impractical. Even with accelerated simulation, the time to completely simulate an entire underground blowout would be many hours. In addition, the advantage of the participant making the decisions and implementing them would not be possible if the participant were forced to match the course of events in the actual case history. Finally, setting up a simulation requires creating a set up or "snapshot" file. This inherently means that the simulation will begin with a set of conditions that are valid at only one point in time.

The point-in-time nature of a training simulation setup means that simulations are best for learning about one decision point. The ability to see the results of that decision even when the well control approach

selected is different than what was done in reality can be an advantage versus a case history review. The validity of those results can be implied both by prior general knowledge about the particular approach chosen and by showing that the simulator would match reality if the historical approach were taken.

A logical design for a case history-based training simulation is to select a key decision point or turning point situation in the history as the point in time for creating a snapshot. More than one decision point can be used from a given case history, but this usually necessitates different snapshots that will be the basis for simulations with different beginning points. The exact beginning point conditions must be selected and entered into the simulation-snapshot file. These conditions can be selected as the situation at or just before the actual decision point. If before the decision point, the participants must be instructed to begin the simulation in a way that forces them to reach the decision point under the same circumstances as in reality. However, this can provide a means for the participants to identify a developing problem and the need to make a decision themselves rather than having it pointed out by an instructor. This can be an important part of the learning process and can reinforce the importance of factors like kick monitoring and detection by first-hand example. Overall, simulations can be used to reinforce a key point, to show how a problem evolves, to practice real detection and avoidance, to analyze alternative kill methods, to practice non-routine kill methods, or to recreate the experience of one portion of a serious event.

A script is usually necessary to complement the simulation snapshot. This provides background information on what has happened before the beginning point and a more complete description of the situation than can be retrieved from the simulator. The script should include:

1. The objectives of the exercise,
2. As much description of the problem scenario as appropriate and necessary,
3. A description of the decision facing the participants if deemed appropriate,
4. Any alternative actions that need mandatory consideration prior to making the decision,
5. Which snapshot file is to be used for the simulation,
6. Any specific procedural steps that are necessary to start and conduct the simulation, especially if necessary to get to a decision point that matches the actual case history,
7. Any specific record keeping, discussion, or reporting requirements during the simulation, and
8. Specific instructions as to how and when to terminate the simulation and how to collect data from the simulation if necessary.

The problem scenario description should include the historical context for the situation. The general geologic and geographic setting, the reason for drilling the well, and recent operational history leading to the current point in time must usually be given. Facts such as the fracture gradient and depth at the previous casing point, the bit size, the mud type, the BOP stack and casing pressure rating, the pump pressure relief valve setting, and the well geometry should all be given. Generally, these items may be difficult or impossible for the participant to determine only from data within the simulation itself. Any recent or anticipated complications should also be acknowledged. A wellbore schematic and a kill sheet should also be included. The leader may also reinforce or supplement any information that will help guide the participants.

The results of simulations can form the basis for more learning by discussing the results of different actions taken by different groups. Therefore, the leader may also request that participants discuss their well conditions during the simulation or participate in discussions to compare results after the simulations. In some cases, it is useful to give different point-in-time situations or different instructions to separate groups in order to create the basis for such discussion.

TRAINING MODULES

Interactive exercises and training simulations can provide learning experiences suitable for either groups or individuals. Both have been developed and used in this project. Interactive exercises emphasize thinking and analysis whereas simulations involve taking continuous action and learning from monitoring the results.

The four modules developed in this project are based on the case histories described in Chapter 4, “Underground Blowout Case Histories.” The first module is an interactive, group learning exercise based on the case history of an underground flow offshore Texas. Participants consider alternative actions at key decision points and the expected consequences of those actions, and then review what actually happened. The second module is an interactive, computer-based, programmed learning exercise. It is based on the same case history and requires similar decision-making by the participant, but does not require an instructor or group discussion. The third and fourth modules are computer-based training simulations. The third uses a simulation of a hard-to-detect, swabbed-in kick to reinforce the importance of careful monitoring and proper, timely reactions as a key to preventing the large kicks that often cause underground blowouts. It is based on the swabbed-in kicks that were the causes of an underground blowout in a deep gas well and a near miss. The fourth module is a simulation that recreates the conditions for a kick taken while drilling with a low kick tolerance. It provides a basis for both reinforcing the importance of rapid identification and control of a kick in these circumstances and for practicing the non-routine methods required when lost returns occur after shutting a well in on a kick. The fifth module includes five simulation setup files recreating decision points in an underground blowout. This module was not completed.

A previous interim report¹⁰ noted that LSU was acquiring an advanced rig floor simulator for well control training. The manufacturer repeatedly delayed the delivery of this simulator. A 3-D, portable simulator was accepted as an alternative and was delivered in March, 1998. In addition, LSU purchased eight copies of standalone PC software for well control training from a separate source. The PC software has proven to be more adaptable to the conditions of an underground blowout and was used as the platform for the simulation-based modules described herein.

Module 1 – Interactive, Group Learning Exercise

The training module, “An Underground Flow Offshore Texas, A Case History-Based, Interactive, Group Learning Exercise – Module 1,” is included as Appendix A. It is a PowerPoint® presentation, Module1.ppt, with detailed instructor notes for each slide to guide its use as an interactive, group training module. Instructors may also wish to review Module 2 as preparation for leading a group exercise with Module 1.

The training module focuses on the critical decisions that became turning points in the efforts to control the well. Both failures and successes are reviewed. These key decision points in this case history are the basis for learning exercises built around this experience and are listed in Table 1. The module introduces the problem with the kicks taken in the sixth well and describes how the conclusion was reached that an underground flow in the fifth well was the most likely cause. It then shows the reproductions of the logs run in the fifth well, see Figure 6 for the temperature log, that confirms a problem exists. This provides the basis for demonstrating that the remaining discussion is not hypothetical, and that a serious problem threatened both drilling safety and the economic value of the field.

| Phase | Critical Issue/Turning Point |
|---------------------------|---|
| Planning & Preparation | Risk of lost circulation with small clearances identified |
| Avoidance | Procedures and monitoring used during lost circulation are not known |
| Detection | Uncertain how fast problem was detected |
| Reaction | Proper shut in procedure used |
| Attempted Control | Improper use of "driller's method" |
| First Loss of Control | Not acknowledged until later |
| Attempted Recovery | Incomplete, only isolated flow from the surface but did not stop the flow |
| Confirmation | None attempted |
| Continued Loss of Control | Inferred by kicks in later well, confirmed with logs |
| Second Recovery | Each step engineered, monitored during implementation, & evaluated |
| Final Confirmation | Careful comparison of logs before and after recovery |

Table 1 - Summary of Critical Issues and Decisions in Case History of Underground Flow

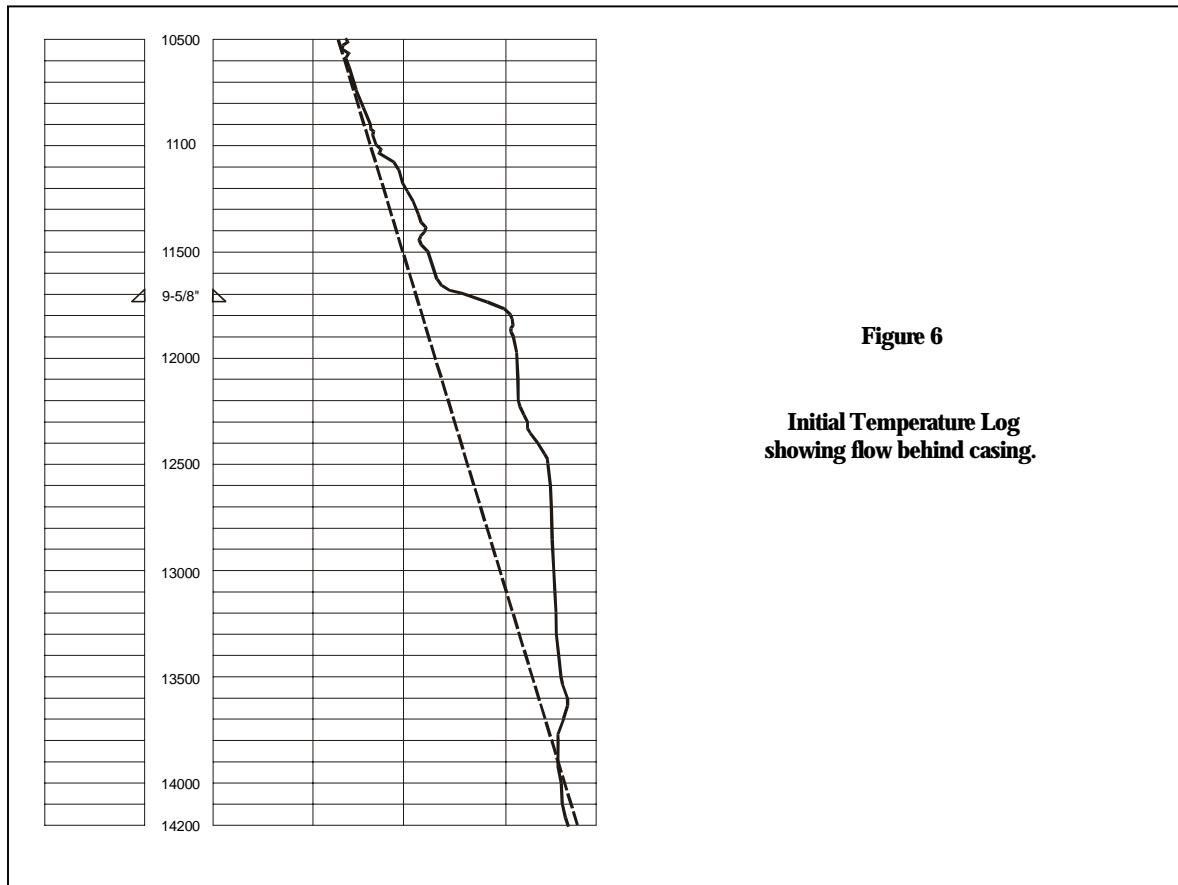


Figure 6
Initial Temperature Log
showing flow behind casing.

The case history describes the operator's experience drilling two moderately deep, highly overpressured gas wells that were the fifth and sixth wells on a platform offshore Texas. An underground flow occurred in the fifth well after cementing the production liner, but was not detected until after unanticipated kicks were taken in the sixth well. Diagnosis with cased hole logs then confirmed the existence of an underground flow behind pipe in the fifth well. A dynamic kill was designed and was followed by several remedial cementing efforts that were eventually successful in isolating the producing zone from shallower, weaker formations. The module then shifts back in time to the planning and drilling of the production interval in the fifth well.

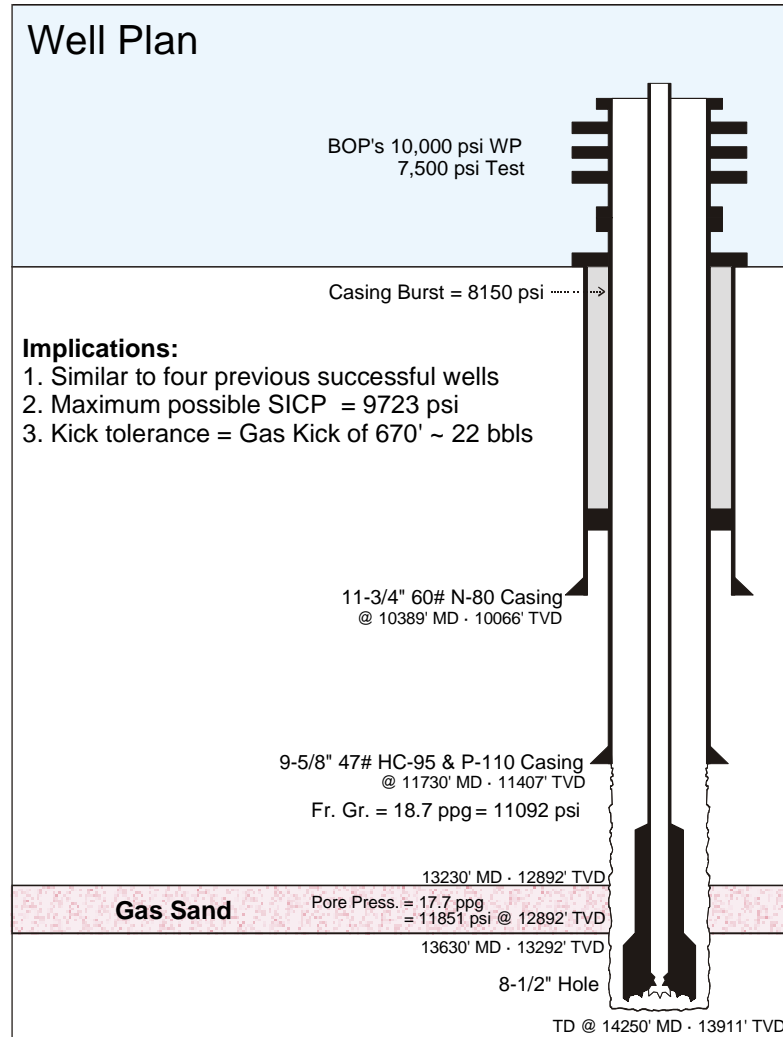


Figure 7 - Wellbore Diagram Showing Well Plan

An overview of the well design, reservoir and fracture pressures, casing design, and kick tolerance are provided using Figure 7. The practical feasibility of the design is validated by the four previous successful wells, but the critical nature of the well is also evident. This provides emphasis on the planning and prevention phases of well control. That emphasis is continued in a discussion of the design and implementation of running and cementing the production liner. Loss of returns during both running and cementing operations is identified as a probable turning point issue in the loss of well control.

Figure 8 summarizes this situation noting that there was no record that the annulus was kept full and that a drop in fluid level of only 140 feet would have caused an influx of gas. After placing the cement, the drillstring was released from the liner, and the well was reverse circulated. After reversing out, the well was identified as flowing and was shut-in with 150 psi on both the drillpipe and the annulus.

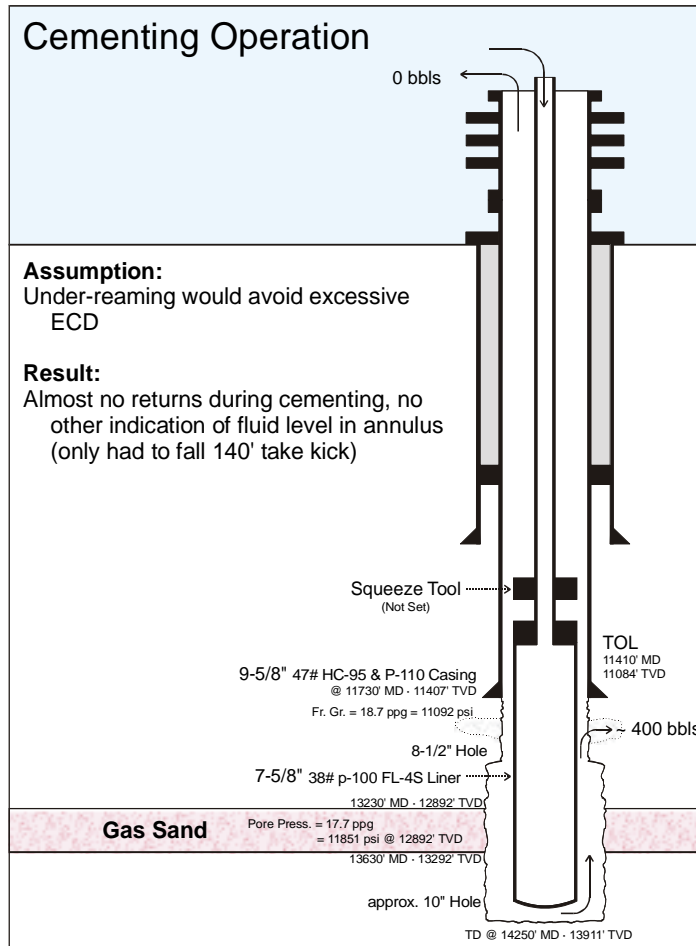


Figure 8 - Wellbore Diagram Showing Production Liner as Run and Cemented

The decision concerning how to control this pressure and recognizing evidence of flow is the first critical turning point addressed using the full “minds-on” learning sequence outlined earlier. Diagnosing the cause of the pressure and flow and selecting and implementing a control procedure are exactly the kind of actions for which rig site personnel are expected to have the primary responsibility. The potential for the pressure being caused by flow back from an induced fracture is to be considered, diagnostic methods defined, and the conclusion that a kick has occurred confirmed. The alternative control actions can be identified and discussed, and then compared to the actual actions taken in the well.

In reality, an attempt was made to remove gas from the well by circulating using the driller’s method. If not already analyzed, this alternative can be discussed before revealing its results. Those results were increasing pit gain and annulus pressure. If the group has not identified the probable failure of this method, the reason for failure can be explained. It provides the key learning that off-bottom control methods are more complex, and require more engineering, than conventional well control.

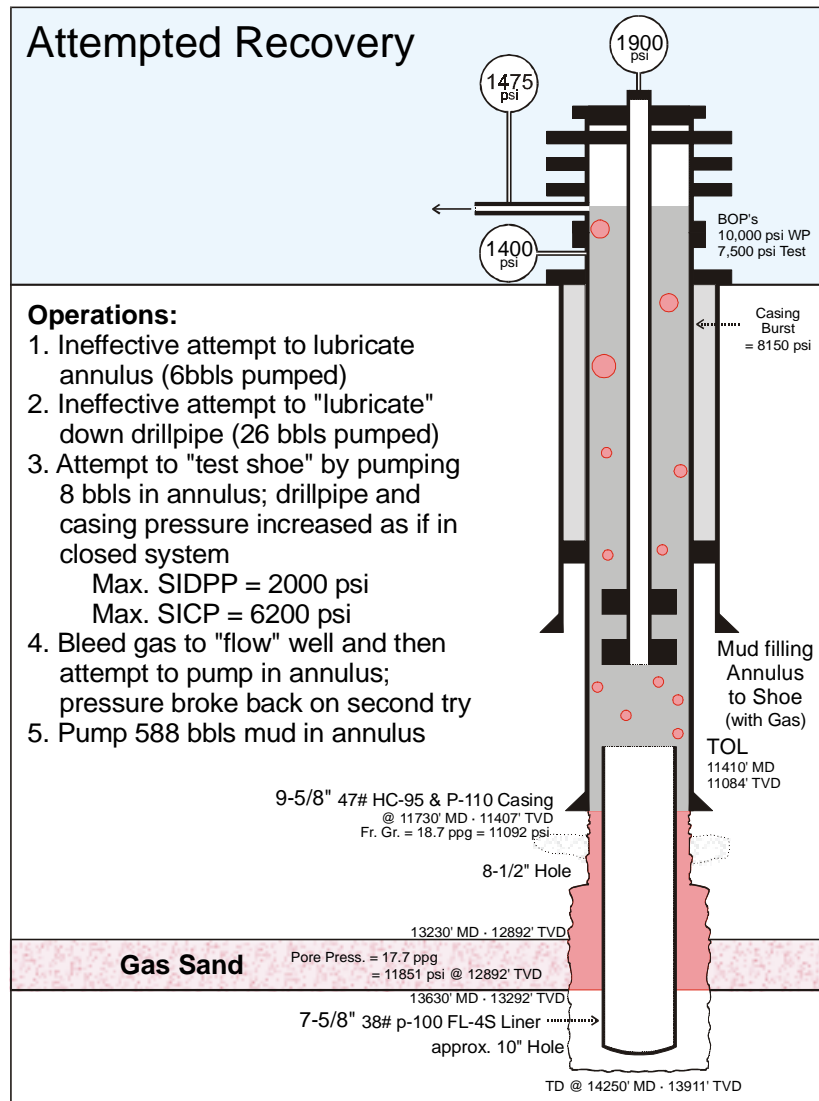


Figure 9 – Wellbore Diagram showing results of bullheading Mud down the Annulus

Recognizing that the situation was worsened by attempting an off bottom Driller's method circulation provides the opportunity to make another key decision regarding how to regain control. The learning sequence can be applied again to a situation where the risk to the rig and its personnel has become significant and "conventional" well control is obviously ineffective. Participants' ideas can be compared again to the actions actually taken and conclusions drawn about why various approaches might or might not succeed. The actual results are shown in Figure 9. The practicalities of bullheading large volumes at relatively high pressures can be reviewed if not previously brought out in the discussion. The pressure on the 9 5/8 inch by 11 3/4 inch annulus is also pointed out. The key learnings are that even a near failure can be reversed and improved and that bullheading can be an effective way to regain hydrostatic head, reduce surface pressures, and improve safety margins.

At this point the pressures on the well have been reduced and another decision must be made. The learning sequence is applied in a cursory fashion to the decision whether to continue bullheading in an attempt to kill the well or to squeeze the liner top to eliminate pressures inside the well. These alternatives are critiqued, and the field results of squeezing cement into the liner top shown in Figure 10 are reviewed.

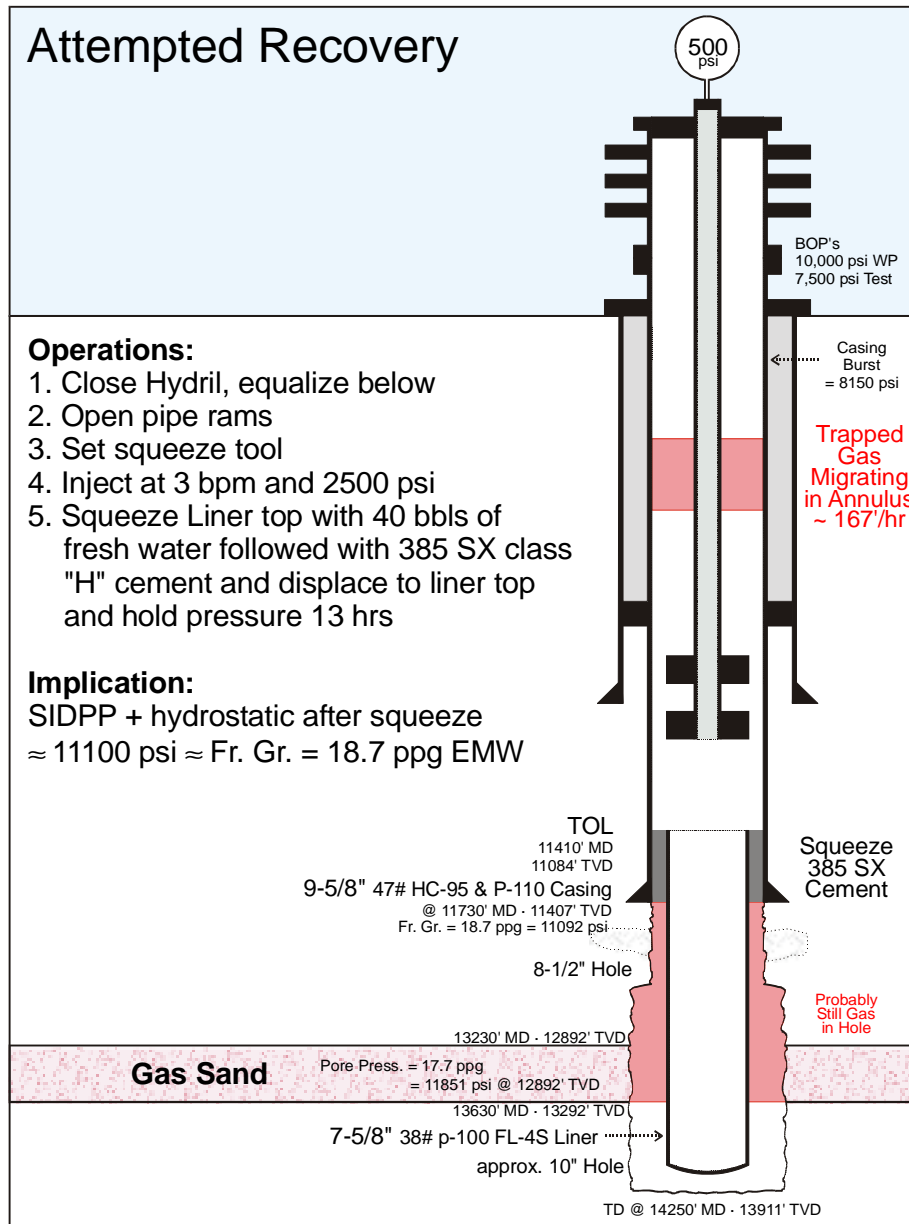


Figure 10 - Wellbore Diagram Showing Results of Squeezing Liner Top with Cement

The next critical decision is whether the liner top squeeze has successfully controlled the well. The learning sequence can be applied again, beginning with brainstorming ways this question might be answered. The methods can then be evaluated relative to what they really measure and how that relates to flow conditions

that might be possible in the well. If participants were paying attention at the beginning, they will remember the logs at this point. This is a good opportunity to bring out the value of both technical methods like temperature and noise logs and operational methods like pressure tests to answer the question more completely than either one by itself can. The actual success testing the liner top and the decision that no further evaluation was necessary lead back to the point where the module began with discovery of the underground blowout affecting the adjacent well. The key learning is that there needs to be real confirmation that control has been reestablished before saying that a well control operation is complete.

Knowing that flow exists behind the liner, the final critical decision is how to regain control. The learning sequence can be applied again to compare the alternative methods listed earlier for application to this situation. This should lead to the more specific questions: "Should the well be killed or bridged and with what?" We are also faced with the question of how to reestablish a flow path to the area of flow and minimize the increase in risk to the rig when we do. Answering these questions requires the integration of engineering and operations again. The predictions of maximum possible gas flow rate and minimum required mud kill rate shown in Figure 11 show how engineering can help provide the answers. The key learning is that, with time and engineering resources, the success or failure of a particular approach can be predicted, allowing design corrections before making a mistake.

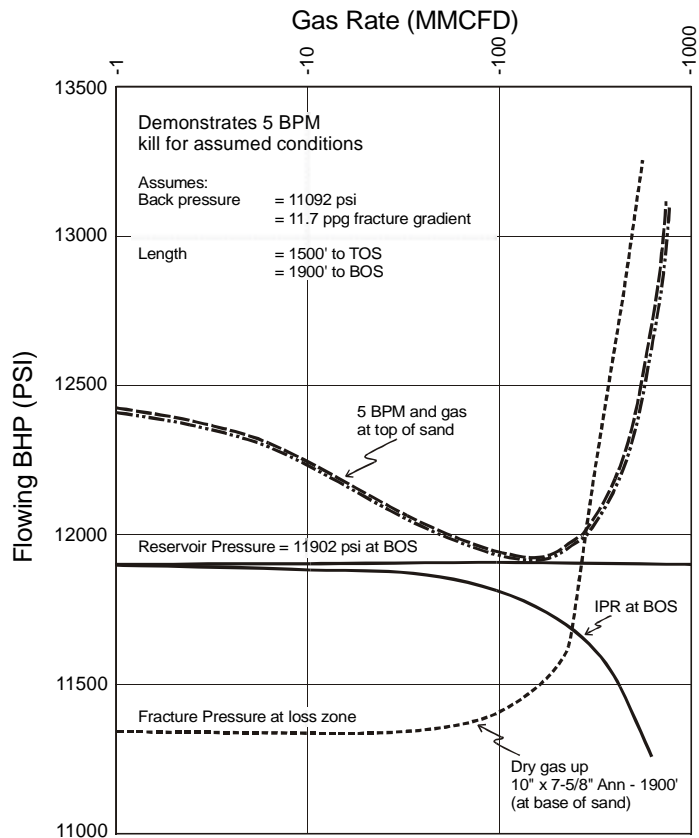


Figure 11 - Prediction of Bottom Hole Pressures and Gas Flow Rates in Annulus

Knowing that a dynamic kill for even worst case flow was feasible, communication with the annulus was reestablished through the casing shoe. Mud and then cement were pumped resulting in a partial cement job on the producing interval. Results were confirmed with logs showing that there was potentially still some flow and that zonal isolation had not been achieved. The casing was perforated and multiple additional cement jobs were placed at the top of the producing sand until it was isolated from the shallower annulus and loss zone as seen in Figure 12. Learnings were that:

1. cement should be expected to move with the fluid flow,
2. tracers can confirm cement placement,
3. achieving a seal or bridge is very difficult in the presence of any flow,
4. leaving the flow path open by over-displacing the perforations greatly reduced the time required between jobs, and
5. repeated jobs would eventually fill and seal channels.

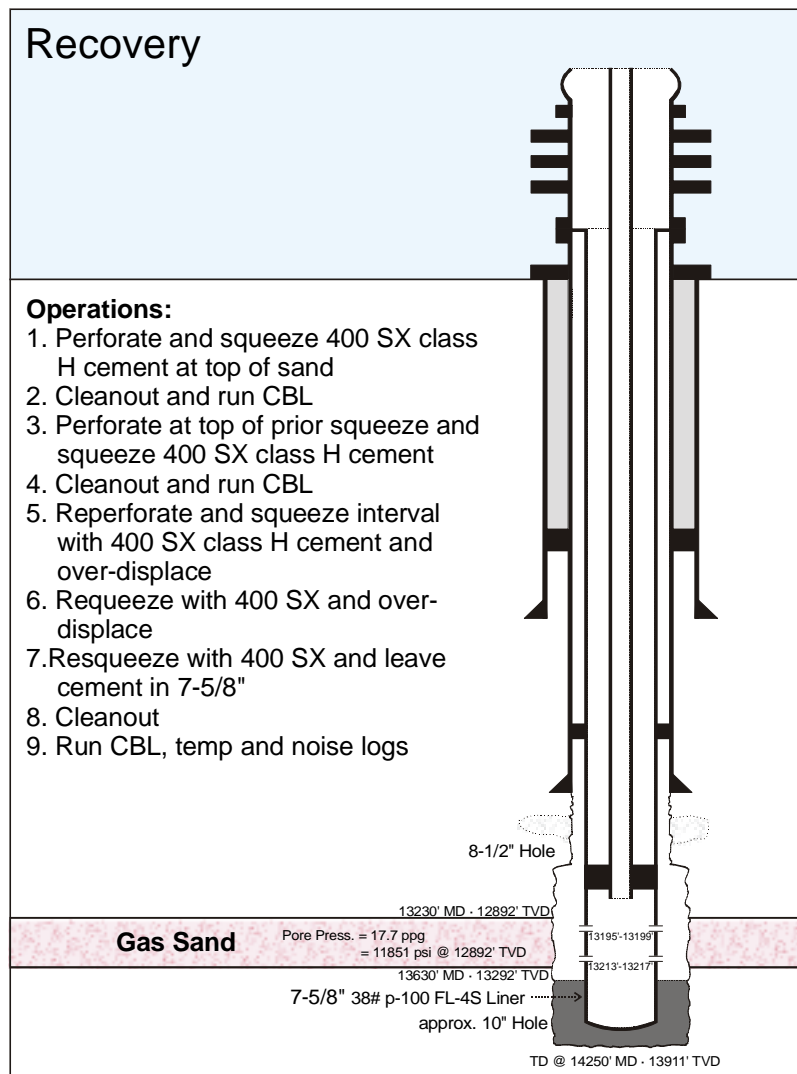


Figure 12 - Wellbore Diagram Showing Cementing Operations at the Top of the Producing Sand

The confirmation with temperature, noise (see Fig. 10), and bond logs of almost complete elimination of flow behind pipe and zonal isolation between the producing sand and shallower zones completed the well control process. The overall learnings are that even apparently minor well control incidents can result in expensive and dangerous uncontrolled flows when handled ineffectively and that conversely, even serious mistakes can be corrected with careful planning, execution, and monitoring. A summary to reinforce the critical issues and turning points in this experience, such as Table 1, is used as the conclusion of the training module.

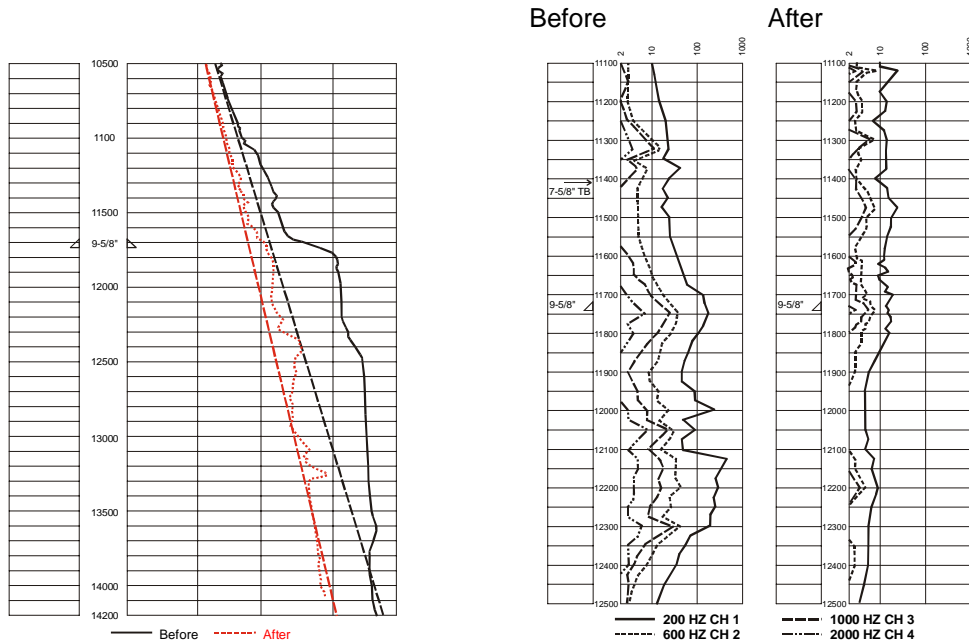


Figure 13 - Noise and Temperature Logs Showing Major Reduction of Flow Behind Pipe

The prototype module has been used four times with rig site personnel as part of pre-well training for drilling HTHP wells in the same area where the incident occurred. Working through the case history with rig site and engineering personnel required 1 1/2 to 3 hours to complete. The case history showed how seemingly reasonable actions can cause big problems and how more rigorous problem solving can correct them. It demonstrated the importance of the rig crew successfully preventing, detecting, and controlling kicks to preclude the much more difficult tasks involved in controlling an underground blowout. It also provided the opportunity for the participating engineering and operations personnel to practice working together to solve difficult problems. As such, it encouraged the continued openness in discussing problems that is necessary for effective teamwork. Subsequently, when real well control situations were encountered, off site engineering resources participated in key decisions and helped analyze and predict the potential consequences of the actions taken. Those predictions were used to help determine whether control attempts were succeeding or an alternative approach was required. The effectiveness of this training and the resulting diligence, planning, and cooperation are evident in the success and the reduced frequency and severity of well control operations in the wells drilled following this training.

The module has also been used five times as a class exercise for a total of about eighty petroleum engineering students taking the well control laboratory class at LSU. The case history reinforced the practical importance of standard well control prevention and detection methods. It also provided an opportunity to practice applying engineering skills and logic as a problem solving team within the context

of a real problem that was not routine. The module has also been used in training about forty industry personnel in MMS-approved well control training. This use had the same logical purpose as for the engineering students, but involved more class discussion of alternatives and practical implications given the much higher experience level of the audience. Participants generally regarded it as one of the most useful components of a one-week course.

Module 2 – Interactive, Individual, Programmed Learning Exercise

Module 2 was designed to be a PC-based, interactive, programmed learning exercise that can be utilized by an individual. This exercise is referred to as “An Underground Flow Offshore Texas, A Case History-Based, Programmed Learning Exercise - Module 2” and is included as Appendix B. It was created by a collaborative effort of the Industrial and Manufacturing Systems Engineering department and Petroleum Engineering department at LSU. The program was written in Visual Basic®, and it runs as a standalone program after being downloaded from either a CD or a remote directory onto the hard drive of a PC. It is intended to be useable with any version of the Windows® operating system from Windows95® through WindowsXP®. The program was designed and written by Eileen B. Hoff and Sherif M. Waly in collaboration with John Rogers Smith, who provided the subject matter content and advice on training design.

The program is structured to guide the user through the case history while requiring the user to make his or her own decisions at key points in the process in a similar manner to the previous module. This module uses the same logic as the group exercise, but it follows a more chronological sequence. The user is presented with a wellbore diagram and facts representing the situation at a given point in time. The user is then requested to make a decision regarding the next course of action to be taken. The decision is made by selecting one alternative from a list of several choices. After an alternative is selected, additional questions concerning the probable outcome may be asked or direct feedback may be given. If an inappropriate response is given or decision made, the user is advised why and given the opportunity to choose again. After the user has selected an appropriate alternative, the user is so informed and an explanation is provided. Then the module advises the user of what decision was made in reality and that decision leads to the next situation and next set of questions.

This module was beta tested with two classes of petroleum engineering students during the Spring 2000 semester. Each of about 30 students progressed through the exercise independently and then submitted recommendations to improve the exercise. Completion of the exercise required about 45 minutes. The students also indicated that a post-exercise discussion was beneficial. It provided a means to clarify their understanding of the factual situations within the case history and to consider the logic used by others in making key decisions.

Based on student recommendations and observations by the authors, improvements were made to both the detailed content and the question sequencing. The improved version is included in Appendix B to this report as a standalone executable program, “mms.exe.” The program includes an introduction to the problem that can be used by both students and instructor. Before an instructor administers the exercise, it is recommended that Module 1 be reviewed by the instructor as preparation for guiding discussion or answering students’ questions. A set of instructions for using the program is also included in Appendix B.

Module 3 – Simulation Exercise for Reaction to Swabbed-in Kick

A third training module has been developed based on the “Near Miss Due to Small Swabbed Kick” case history. It is intended to demonstrate how a small swabbed-in kick can be very difficult to detect but can develop into a blowout if ignored for too long. The scenario used is also representative of the kick that caused the “Underground Blowout in Deep Gas Well^{13,14}.” The exercise is currently implemented on standalone, PC-based, well control training simulation software developed by Drilling Systems (U.K.) Limited. The software is DRILLSIM 5 Version 1.66.

The training exercise begins by advising the students that they have just arrived on the rig for a crew change. A trip from Total Depth (TD) has just begun and the third stand is being pulled. The floorhand monitoring the continuous-fill trip tank has advised that the hole has taken at least two barrels less mud to fill the hole than calculated. The supervisor they are relieving has just requested that the trip be postponed and the well watched for flow. The students must then perform the flow check and decide what to do next. They should not be told that the well has kicked. Ideally, they should have the same uncertainty about the meaning of a small volume discrepancy that they would have in a real situation.

There are a number of alternative actions the students might take after observing that there is no flow. Some of the possible reactions are:

1. Assume this is the effect of a slug falling and continue the trip out of the hole,
2. Assume the lack of fillup volume is in fact a kick and shut the well in to begin circulating out on the choke,
3. Attempt to circulate bottoms up with the bit nearly 300 feet above TD,
4. Trip in hole to TD and circulate bottoms up, or
5. Leave the well as-is and watch for any evidence of flow over some set time.

There are additional various reactions that might be taken as the students observe the results of their decision. In any case, careful observation will eventually demonstrate that a kick has in fact been taken.

A major objective of this exercise is to allow the student to reach the conclusion that there is a kick in the well independently of confirmation by the instructor. This shows that the presence of a small, swabbed-in kick is initially almost impossible to confirm conclusively. In a water-based mud, a gas kick will usually migrate until the size of the individual gas bubbles are small enough to be held by the gel strength of the mud. Since most kicks contain at least some free gas, migration is likely, and as the gas migrates, it will expand. The expansion is very slow while the kick is migrating in the lower section of a deep well, and the resulting pit gain is too slow to detect. As the kick reaches the upper portion of the well, the previous expansion will have resulted in a larger kick volume. The hydrostatic pressure at the kick will also be changing proportionately more rapidly, so the kick will be expanding more rapidly even if the migration velocity stays relatively constant. A more rapid expansion, or the formation influx due to the well becoming underbalanced will eventually result in detectable flow and significant pit gain at the surface. If identified quickly enough, the well can still be shut-in and controlled. In the actual case of the “near miss,” control was regained without great difficulty. In the “deep underground blowout,” it was misjudged for too long, and became an underground blowout essentially as soon as the well was shut in. However, this was still less dangerous than a surface blowout.

The training exercise has given similar results. It has been used in training over twenty industry professionals. Their first reaction is usually to ask the instructor what to do. Because they are in a well control training course, they expect to have to shut the well in. Asked what they would do in the field if

this were a real case, the reaction is usually to carefully check for flow. After identifying that there is no flow, there will typically be one of two reactions. One is to trip back to bottom to circulate bottoms up and check whether a kick was taken. The other is to continue tripping out of the hole. In either case, essentially nothing happens to indicate whether a kick is present until it has reached the upper few thousand feet of the well. Circulating bottoms up will bring the kick up faster, and therefore requires a faster response, but if monitored properly, is much safer than continuing the trip. One independent consultant and operator indicated that he would always shut the well in and circulate out on the choke because of the number of similar situations that have resulted in blowouts.

The simulation is of a 3 barrel swabbed-in kick in a 10,000 foot well. This was selected to simulate the effect of an even smaller kick that had migrated to 10,000 feet in a deeper well. The 10,000-foot depth was chosen to reduce the total amount of simulation time. A wellbore diagram for the simulation is shown in Figure 14. In the actual case histories, the flow was not detectable until after more than ten hours of migration. The simulation demonstrates this effect with a much shorter period of apparent inaction. Even so, one team of students had an experience similar to the deep underground blowout. Apparently, the lack of any “action” during the early part of the simulation caused them to become distracted. They missed the initial indications that the well was flowing and that a pit gain was occurring.

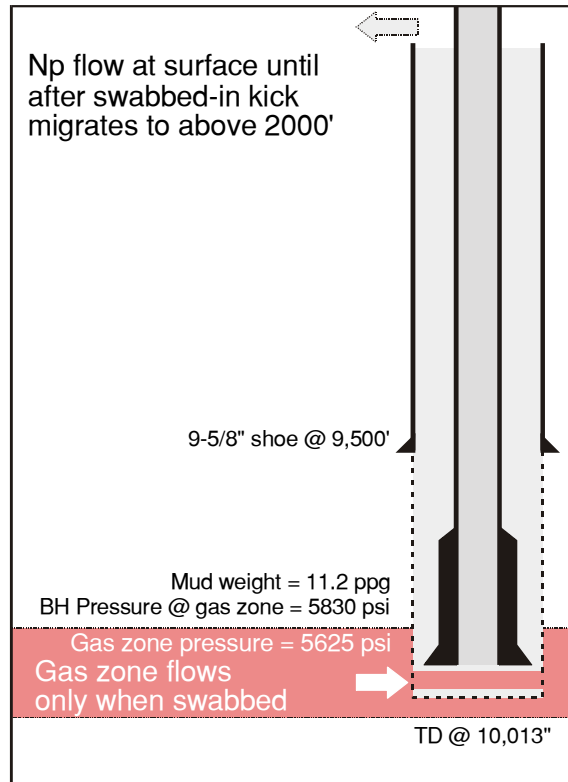


Figure 14 - Wellbore Diagram for Simulation of Swabbed-in Kick, Module 3

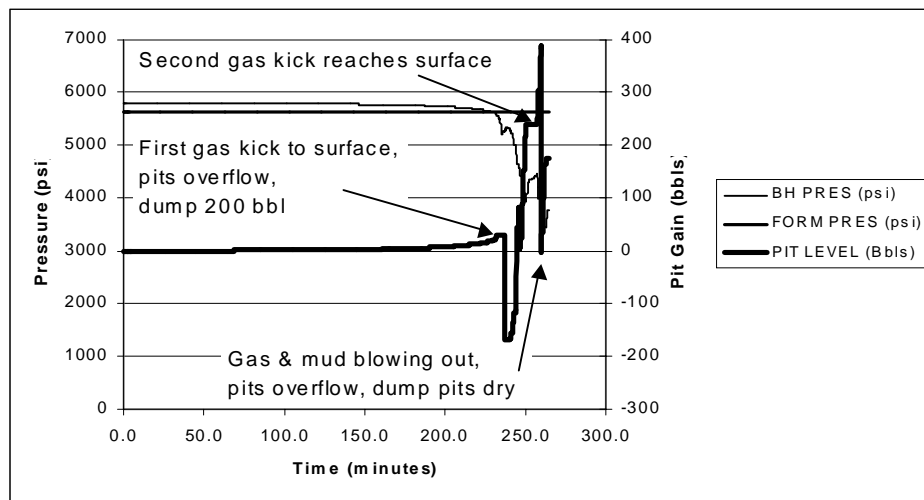


Figure 15 - Pressures and Pit Gain from Simulation of an Uncontrolled Swabbed-in Kick

The pits eventually overflowed causing the simulator screen to flash red. The simulator was “frozen” in order to prevent the simulation from blowing out rather than taking a practical action.

Figure 15 is an example simulation of the subsurface pressures and the pit gain versus time recorded for uncontrolled migration during a trip that ultimately results in a blowout. Note that once the well becomes underbalanced, it unloads more rapidly and wellbore pressures drop rapidly. The reduced pressure causes an increased rate of flow into the well. In the simulation, several hours are required for the gas to migrate to a depth of about 2200 feet, where the gas has expanded enough to cause a 10 barrel total pit gain. Within another 10 minutes, the kick has migrated to about 1300 feet and expanded enough that the well becomes underbalanced and the formation begins to flow. After an additional 10 minutes, the gas reaches the surface. In the actual case of the “Underground Blowout in Deep Gas Well,” enough additional kick had been taken before shutting-in that the shut-in casing pressure caused lost returns initiating the underground blowout essentially as soon as the well was shut-in.

The most common reaction by industry participants has been to use the precautions commonly taken in the field. They trip back to bottom and begin circulating bottoms up to check whether there are kick fluids in the well. Again, there is very little “action” initially. However, the 69 minutes required to circulate bottoms up only requires 7 minutes at X10 on the simulator. So, the kick reaches the upper portion of the well fairly quickly. A gradually increasing pit gain warns an observant team that there may indeed be a kick in the well. Depending on how rapidly the team detects this, a flow can usually be observed if the pumps are stopped to check for flow. If so, the well is shut-in, and conventional well control is begun. Given that the well already contains kill weight mud, a driller’s method approach can be used to remove the kick and refill the well with mud. This approach is usually successful and fairly uneventful. The casing pressures and pit gain observed during this procedure reconfirms that a kick had been taken. Figure 16 is an example of the pressures and pit gain versus time recorded in a simulation of this sequence of events.

Three key learnings can be provided through this exercise:

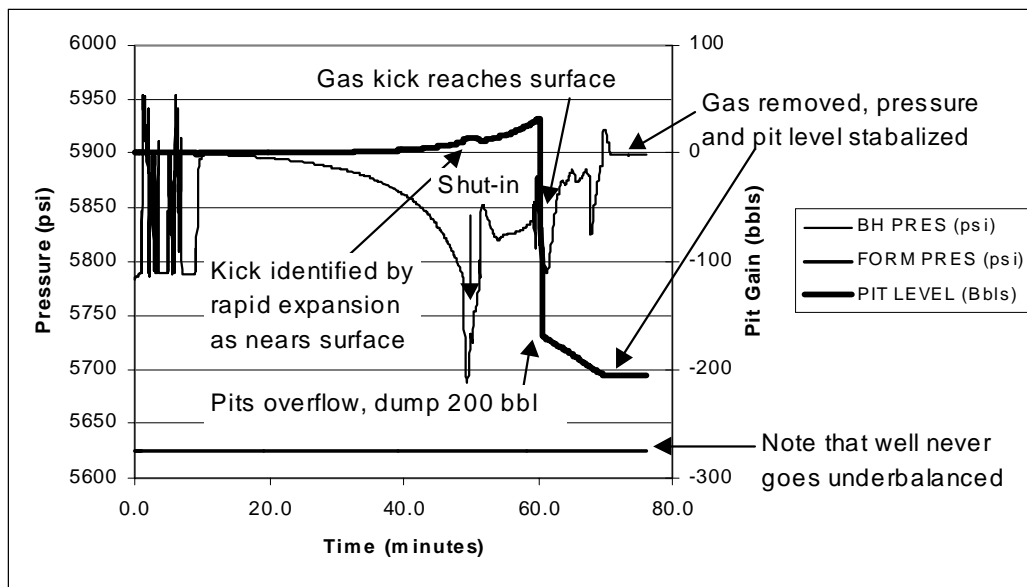


Figure 16 - Pressures and Pit Gain from Simulation of Effective Control of a Swabbed-in Kick

1. A small kick in an overbalanced well, as from swabbing, is very hard to detect. After the simulation, calculations of hydrostatic pressures in the well can be done to demonstrate why this is true.
2. The critical responsibility when circulating bottoms up to check for a kick or when continuing a trip after an inconclusive kick indication is to keep monitoring kick detection parameters. If a small gas kick is being brought up in a deep well, eventually it is likely to cause enough loss of hydrostatic for the well to begin flowing.
3. The period during which the kick can be identified and shut-in safely may only be a few minutes. Failure to react rapidly and appropriately can cause loss of control.

Given that many kicks occur on trips and that blowouts and underground blowouts have resulted from some of these kicks, we believe that this is an important learning exercise to supplement more routine exercises.

Appendix C includes a snapshot file, Mod3swab.snp, to initiate this simulation in DRILLSIM5. Instructor notes include a problem description and a summary of problem set up parameters, a set of student instructions, a blank data sheet for student records, and a completed example kill sheet for this module.

Module 4 - Simulation Exercise for Kick Taken with Low Kick Tolerance

A new training module has been created to simulate the “Kick Taken while Drilling with Low Kick Tolerance” case history. It is intended to recreate the experience of taking a kick with a high risk of becoming an underground blowout. It allows the participants to practice kick identification, flow check, shut-in, pump start up, and kick removal with any of several alternative kill methods. Depending on the volume of gas allowed to enter the well and the kill method chosen, a complete successful kill may be simulated. Thus this exercise can recreate the basis for any of the key learnings in this case history, although it is unlikely that a single simulation will support all of the key learnings.

This near miss case history was chosen specifically to provide opportunities to avoid an underground blowout by either rapid implementation of conventional kill methods or by applying basic hydraulic calculations to “non-conventional” kill methods. The drill string being near bottom in this case means that drillpipe pressure can be used as an indicator of bottomhole pressure as in conventional well control. Consequently, drillpipe pressure indicating a bottomhole pressure greater than measured at initial shut-in conditions can be used to indicate that the kick formation is being controlled, even for non-routine methods. Practice preparing a conventional kill sheet is part of the exercise and is helpful for determining the drillpipe pressure and volumes to be pumped even for non-routine methods.

The exercise begins with participants being advised that they are drilling a moderately deep well that is approaching a liner point in a transition zone below intermediate casing. This simulation is based on an actual kick taken offshore Louisiana while drilling with a 16.2-ppg mud and a 16.9-ppg measured leak off test at the intermediate casing shoe. The SICP increased to 3160 psig over 8 hours while mixing kill weight mud after the actual kick. “Non-conventional” well control methods were used to successfully control the well. Participants will drill into this same zone and have the opportunity to make decisions and take actions to avoid such severe consequences.

After drilling into the kick zone and shutting in the well, participants are asked to consider the following alternative responses if returns were lost after shutting the well in:

1. Driller's method,
2. Wait and weight method,
3. Bullhead down drillpipe,
4. Bullhead down casing,
5. Bullheading combined with subsequent circulation on choke,
6. Bullheading drillpipe and casing simultaneously, a "sandwich" kill,
7. Low choke pressure method, or
8. Volumetric control.

Participants may implement any of these actions that they consider appropriate. They are prompted to consider other ideas and to plan their reaction. Specific considerations should include:

1. What mud weight to use?
2. What volume to pump?
3. What pump rate and pressure?
4. When to start pumping?
5. When to stop pumping?

Once they begin simulating, they are asked to remember that they can always stop pumping and close to choke to check static pressures. This action will provide a simpler view of what is happening in the well to determine if they are losing control.

Several teams of industry professionals in well control schools at LSU have worked through this exercise. Each team identified the kick, shut the well in very quickly, minimized kick size, and was able to control the well with careful application of conventional drillers' or wait and weight methods. These simulations show the advantage of a rapid response to a kick because it minimizes the kick size and improves the chance of getting a relatively straightforward kill.

The author has simulated several of the alternative well-control methods listed in this training module. Both bullheading and circulation alternatives can be successful. Three criteria must generally be met. First, the pressure at the casing shoe must be maintained at or near the fracture pressure to maximize bottomhole pressure. Second, the hydrostatic pressure gradient in the open hole annulus must be increased by pumping heavier mud in through the drillstring. Third, the gas must be removed from the casing annulus, either by circulating out against a choke or by bullheading down the annulus into the formation below the casing shoe.

Well behavior in the simulation of a sandwich kill, pumping simultaneously down the drillpipe and the annulus, was roughly similar to the well behavior during the actual kill in the field. This simulation was conducted based on a snapshot file of a shut-in well after taking an 11-barrel kick. Consequently, the underground transfer of fluids has already begun at the start of this simulation. The initial shut-in drill pipe pressure (SIDP) in the simulation that the snapshot was based should have stabilized at about 340 psig. However, the shut-in casing pressure (SICP) built up rapidly due to the size of the kick, and the casing shoe broke down as it exceeded about 360 psig. The SIDP had decreased to 285 psig and the SICP built to 804 psig by the time the simulated kill began. In actuality, the initial pressures recorded in the field were a SIDP of 375 psig and a SICP of 260 psig. However in the field, the kill was not begun until about 9.5 hours after initial shut in. At that time, the SIDP was about 275 psig and the SICP was about 3300 psig.

The simulation gives a relatively realistic learning experience. The SIDP at the beginning of the simulated kill is similar to that in the real kill. The fluid density of 16.8 lb/gal and the drill pipe pump rate of 1.7

bbl/min and annulus pump rate of 3.0 bbl/min for the simulation were selected to match that used in the field.

Figure 18 is a plot of pressures and the combined pump rate, for both the drillpipe and the annulus, for the simulation of the sandwich kill. Note that the drillpipe pressure begins increasing relatively quickly after the simultaneous bullheading down the drillpipe and casing began. The expected slow circulating rate pressure at 1.7 bbl/min is about 80 psig. Therefore the expected initial circulating pressure to achieve a kill is about 420 psig. As the drillpipe pressure increases to a value greater than this in the simulation, the formation is overbalanced, and the well becomes controlled. This provides confirmation that the kill is succeeding. The final drillpipe pressures during and after the simulated kill are roughly similar to those recorded in the field. The choke pressures are lower than recorded in the field because of the large amount of gas that had built up in the annulus in the field during the shut-in period. At the end of the simulation, bullheading was terminated, trapped pressures were bled off, and the well was dead, as confirmed by bottomhole pressure being greater than formation pressure.

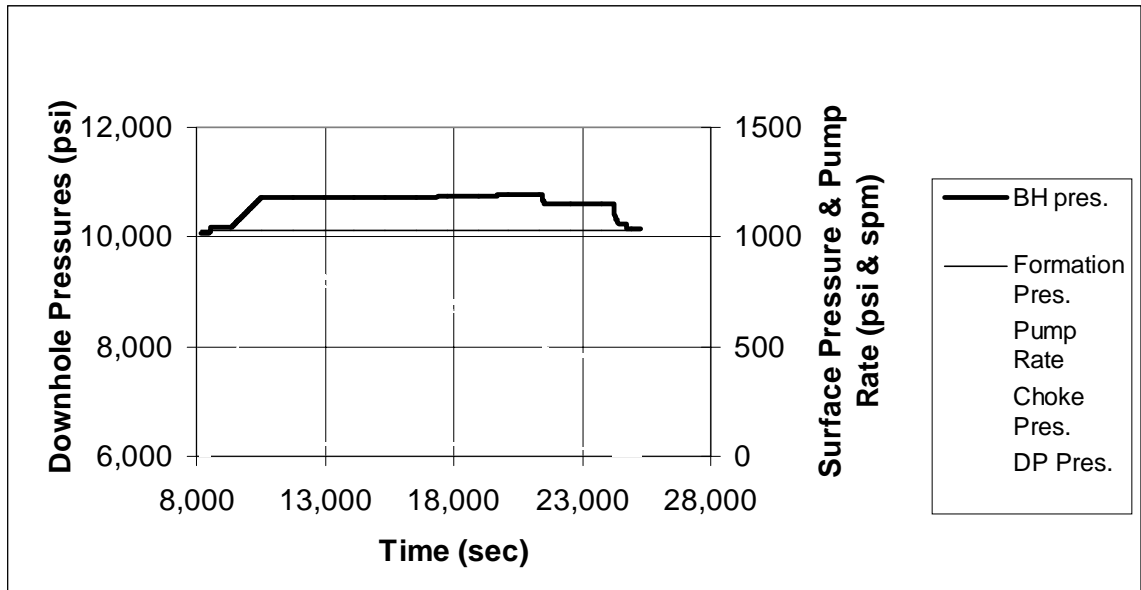


Figure 18 - Simulation Results for "Sandwich Kill" of Kick with Low Kick Tolerance

Additional simulations by the author for this same case showed the feasibility of an essentially conventional kill despite lost returns if implemented before an underground flow was severe and also the fallacy of attempting the "low choke pressure method." Specifically, pumping at a rate of 68 strokes per minute a conventional kill was possible just by leaving the choke closed until gas was displaced above the casing shoe and drillpipe pressure increased to the initial circulating pressure. Conversely pumping at the same rate while opening the choke to try to reduce choke pressure below the 360 psig limit only caused additional influx and increased the casing pressure after a very short period of time.

These simulations show both the feasibility and the value of conducting training simulations of non-routine well control approaches where results can be validated by comparison to an actual field case history. While such simulations are unlikely to give an exact history match, the simulations conducted on the DRILLSIM 5 did provide practice of the procedural steps and simulation results that were reasonably similar to what could be expected in reality. In addition, the simulations can be used to reinforce the

importance of rapid detection and to see how having on-bottom circulation allows adaptation of conventional kill methods to a kick with induced lost returns.

Appendix D includes two snapshot files, Mod4KT.snp and Mod4Ktsi.snp, to initiate these simulations in DRILLSIM5. Instructor notes are provided that include:

1. a problem description and a summary of problem set up parameters,
2. a set of student instructions including questions and problems,
3. a blank data sheet for student records, and
4. a completed example kill sheet for this module.

Simulation Exercises for Control of Large Swabbed-in Kick Leading to an Underground Blowout

A substantial amount of effort was expended towards creating a fifth module based on the case history of an “Underground Blowout in a Deep Gas Well.¹³”. Ultimately, development of this module was halted after the project deliverables were revised to four modules instead of five so that other project tasks could be expanded. Jason Tilley, an undergraduate student, created multiple simulation snapshot files to recreate the decision points in this case history as his senior project before graduating. This project was very time consuming due to the trial and error nature of trying to force a simulation to reach the same set of conditions that existed in the field at a given point in time. Given the difficulty of creating these files and the similar or greater difficulty to duplicate them on other, more common, training simulators, the effort to create a formal module was discontinued.

The simulations envisioned for this module were intended to recreate the major decision points and actions that resulted in the underground blowout and that ultimately brought it back under control. Recreating the entire case history in a single simulation would be very time-consuming, requiring many hours, even at the X10 maximum speed of the simulator. However, by starting at various points in time, various situations that occurred during the case history could be simulated to explore alternative courses of action that might have been taken. Each such situation then becomes a separate learning exercise within the context of the actual events that occurred. This would have allowed the key learnings from the case history to be learned in a “hands-on,” experiential manner by the student or students operating the simulator.

Many snapshot files were created during the attempt to recreate these decision points. Five snapshot files were selected as being especially representative of decision points in the actual underground blowout in a deep gas well. These are included in the electronic version of Appendix E. The files were taken from, and intended to support future, simulations on the Drilling Systems (UK) Limited DRILLSIM5 Version 1.66 training simulator. A summary description of each file is included below. Some trial simulations were conducted by Mr. Tilley and the author to evaluate the utility of these snapshots for training simulations. A summary of the results of those simulations is also provided.

The first key decision point was determining whether the well was in fact flowing on the trip in the hole at 18,400’. The snapshot recreating that decision point is “ugbo-d1.snp.” It results from the simulation of a small, swabbed-in, gas kick migrating from deep in the well. Although the simulation used to create this snapshot was too slow to use during a conventional well control course, it gave results that correspond well with the real events.

The snapshot “ugbo-d1.snp” was taken during a flow check of the deep gas well during a trip in hole at 18,400’. A very slight, trickling flow is occurring due to the migration and expansion of the swabbed-in gas kick. The simulation shows the difficulty of detecting such a kick. However as in Training Module 3, the presence of the kick can be detected if careful observation continues.

A second decision point occurs in the case history when the well was shut-in on the weak flow described in the previous paragraph. The file “ugbo-d2.snp” recreates this situation with the drillpipe still at 18,400’, no drillpipe pressure, but 100 psi on the casing annulus. Simulation of a “driller’s method” kill at this decision point showed that the well is easily controlled.

The third decision point occurs later during the trip in the hole in the actual case history. The file “ugbo-d3.snp” represents a flow check after tripping in the hole to 19,300’ and circulating “to get the mud in balance.” A 73 barrel gain occurred during this circulation. This check represents what would have resulted if one had been made after an actual 73-barrel gain. (In the actual case, this check was not made.) The simulation shows that the well is flowing about 20 barrels per minute at this point. If it is shut in, the SICP is only about 200 to 300 psi. Consequently, a carefully designed, essentially conventional kill can still be achieved. The simulation of such a kill showed that after circulating 18,653 strokes of 12.5 ppg mud on choke, while keeping a circulating pressure equivalent to a shut-in drillpipe pressure above 780 psi, the well was dead. Lost returns during the kill simulation totaled about 100 bbl of mud.

A fourth scenario recreates the situation when the well was shut in the second time in the case history. It shows that the downhole pressures exceeded the known fracture pressure in the Ferry Lake limestone, causing the underground blowout to begin. Similar conditions are present in the snapshot “ugbo-d4.snp.” It represents the conditions after shutting in the well and stripping in to 20,500’ as in the actual case history. (Stripping to this depth was never successfully simulated using the simulator.) The snapshot shows that SIDP = 1190 psig and SICP = 4170 psig. In the case history, bullheading the annulus and filling the drillpipe were used to reduce surface pressures, which did exceed 4100 psi on the annulus at one point.

The fifth and final scenario represents conditions that existed just before a successful dynamic kill. The drillpipe and annulus pressures had been reduced as described in the previous paragraph. This scenario is portrayed by the “ugbo-dk.snp” snapshot file. In this file, the well is set up to initiate a dynamic kill of underground blowout in deep gas well with 13.5 ppg mud by pumping down drillpipe and annulus simultaneously with bit at 20,502 feet. The SIDP = 0 and SICP = 2529 psig. Simulation of the actual kill procedure used in the field resulted in a successful kill, but the simulated pressures did not match the actual pressures. This is probably because the initial conditions in the snapshot, especially the gas distribution in the annulus, did not match the actual conditions exactly. Given that the actual distribution was impossible to determine, it is probably impossible to configure a snapshot that would allow a rigorous evaluation of whether the simulator could perform an exact history match. Nevertheless, a simulation can provide both practice in the procedures used and a qualitative confirmation that use of a well-designed dynamic kill method will regain control of a high rate underground blowout. It should also provide a means for practicing and at least qualitatively evaluating alternative kill procedures.

CONCLUSIONS AND RECOMMENDATIONS

Four training modules have been developed for improved training to prevent and control underground blowouts based on the realism provided by actual case histories.

Conclusions

1. Case histories can provide the basis for a variety of interactive training methods. These factual experiences establish a sense of reality when learning well-control concepts and methods that cannot be achieved with hypothetical simulator exercises or example calculations alone.
2. Module 1 has been used to train over 40 industry professionals and about 80 LSU students. This module has been used to successfully develop rig site personnel's appreciation for the importance of their actions to prevent, detect, and control kicks. It also illustrates the need to coordinate plans with engineers to analyze and predict the consequences of the control actions being taken.
3. A preliminary version of Module 2 has been tested in training about 30 LSU students. It provides a means for an individual to interact with the program rather than with a group and realize many of the same learnings as included in Module 1.
4. Module 3 has been used to train about 20 industry professionals. It is a practical, hands-on, training simulation of the difficulty of detecting small, swabbed-in kicks and the importance of timely detection and shut-in. Comparison of the simulation to actual case histories reinforces this importance relative to the avoidance of large gas kicks that can cause underground blowouts.
5. Module 4 has been used to train several small teams of industry professionals. It is a practical, hands-on, training simulation of the difficulty of handling a kick taken while drilling with a small kick tolerance. It reinforces the importance of rapid identification and control of a kick in these circumstances and provides a means to practice the non-routine methods required when lost returns occur after shutting a well in on a kick. Comparing the results of simulating the case history to the actual results validates the realism of the students' different, independent simulations.
6. Case histories strongly reinforce the importance of preventing, detecting, and controlling kicks as the best approach to preventing and therefore controlling underground blowouts. The importance of seemingly mundane procedures, such as monitoring pit gain while circulating bottoms up or rigorously monitoring hole fill-up or displacement during trips, can be demonstrated with training simulations that are based on actual case histories. The training modules developed in this work require the student to make decisions and take corrective actions as symptoms develop, rather than just practice routine procedures.

7. The DRILLSIM5 simulator has proven useful for training simulations of the non-routine conditions that can lead to, or occur during, underground blowouts. Another manufacturer's training simulator was not successful in recreating the conditions for this kind of training simulation.

Recommendations

1. The training modules included herein should be released for unrestricted use by anyone or any organization seeking well control training materials. A convenient means of such unrestricted distribution would be posting this report and the appendices on an Internet web site.
2. Government and industry should continue to support comprehensive case history analysis of major well control incidents and near misses for identification and distribution of key learnings via reports, conference papers, industry publications, and training modules.

Acknowledgements

The authors appreciate the support and encouragement from the Minerals Management Service for this project. We also thank LSU for its support and permission to publish. This work would not have been possible without the information provided by operators, contractors, and their drilling personnel; it is greatly appreciated. Finally, Jason Tilley, Chandrashekar Hariharan, and Firat Ustun, all contributed to the successful development and use of the simulations and computer-based training modules developed in this project.

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NOTE: A more extensive bibliography covering topics relating to underground blowouts and well control in general is provided in: SPE Reprint Series No. 42 – Well Control, SPE, Richardson, TX (1996).



Appendix A - An Underground Flow Offshore Texas, A Case History-Based, Interactive, Group Learning Exercise – Module 1

This appendix contains the visual aids and instructions for a group, interactive learning exercise on avoiding and correcting underground blowouts based on the case history of an “Underground Flow Offshore Texas.” The appendix is provided in electronic form only and is available for download at BourgoyneEnterprises.com

This appendix contains “An Underground Flow Offshore Texas, A Case History-Based, Interactive, Group Learning Exercise - Module 1.” This exercise is conducted by an instructor leading the review and discussion of the case history. It allows the participating group to consider the circumstances at key decision points in the case history and to draw their own conclusions as to what should be done.

The exercise has been constructed as a PowerPoint® presentation. All of the slides necessary to conduct the exercise are provided in electronic form in the file, Module 1.ppt. Instructor notes with explicit descriptions, questions, and answers are provided for each slide in the PowerPoint® file. If you have a copy of this report on CD, the file “Module 1.ppt” is located in the “Appendix A” folder. If you need to download this file, go to <http://www.BourgoyneEnterprises.com> and click on “LSU/MMS Reports.” The file can then be downloaded by clicking on the “Module 1.ppt” file listed in the software column of Task 10, Appendix A, and then saving the files to your designated subdirectory.

An instructor or discussion leader should review the presentation and instructor notes before conducting a training exercise. Additional preparation can also be gained by taking the programmed learning exercise included in Appendix B and by reviewing the SPE paper entitled “Case-History Based Training for Control and Prevention of Underground Blowouts¹¹.”

Appendix B - An Underground Flow Offshore Texas, A Case History-Based, Programmed Learning Exercise - Module 2

This appendix provides instructions regarding a computer program that provides a programmed learning exercise on avoiding and correcting underground blowouts based on the case history of an “Underground Flow Offshore Texas.”

This appendix provides instructions regarding “An Underground Flow Offshore Texas, A Case History-Based, Programmed Learning Exercise - Module 2.” This exercise is conducted by an individual student running the computer program that is included in the electronic version available for download at BourgoyneEnterprises.com. The following are start-up instructions for running the program.

It is recommended that a separate directory be created on the PC for ease of uninstalling or moving the program later. Verify that at least 15 MB of memory is available on the hard drive. The program has been tested on and should run on Windows® 95,98, NT, and 2000 operating systems. It is expected that it will also be compatible with subsequent Windows® operating systems. Close all other programs. Then, follow the steps below to install the program.

Installation:

1. After the directory is created, copy the following Module 2 files into the subdirectory: “Mms.cab”, “Setup.exe”, and “Setup.lst”. If you have a copy of this report on CD, these files are located in the “Appendix B” folder. If you need to download these files, go to <http://www.BourgoyneEnterprises.com> and click on “LSU/MMS Reports.” The files can then be downloaded by clicking on each of the “Mms.cab”, “Setup.exe”, and “Setup.lst” files listed in the software column of Task 10, Appendix B, and then saving the files to your designated subdirectory.
2. Double click the file entitled “Setup.exe” to execute this program. When the setup program appears, follow the directions to install the program. If the program finds newer version of
3. In the “MMS Setup” dialog box, select the drive and the directory where you want to install the program. If you have created a special directory as recommended, you can install the program in this same directory by clicking the cursor on the “change directory” button. After you select the appropriate drive and directory, it should be displayed in the text box behind the word “Path:.” If the path is correct, select “OK.” If you do not select a specific directory, the program will be installed in the “C:/Program Files/” directory (assuming the C: drive is your primary drive). Note that there will also be additional operating system files installed in the “C:/Windows/System/” directory. The install program will warn you if it finds

newer system files already installed in your “C:/Windows/System/” directory. It is recommended that you click on “yes” to keep these newer system files if they are found.

4. You should now be in the “MMS Setup” box again. Click the cursor on (select) the “PC” icon button on the upper left to continue setting up the program. Do not select the “exit set up” button unless you have really chosen not to install the program. The files necessary to run the program will be installed as described in step 4.
5. When the installation is complete, you will be advised. Then select the “OK” button to exit the program setup. You are now ready to run the program.

Running the program and using the learning exercise is essentially self-guiding. Follow the steps below to get started on the exercise.

Running the program:

1. Click on (select) the “Start” button, and then select “Programs.”
2. Find the “Mms” program in the list of programs and select it. If desired, a “shortcut” can also be installed on the desktop to make starting the program easier. This can be done by right clicking the Mms.exe file and placing a short-cut on your desktop.
3. An “Underground Blowout Training Module” dialog box will open and request a user id and a password. Enter “user” as the user id and “password” as the password. Select the “OK” button.
4. The program will open with the title page. Select the “continue” button. You are now running the program.
5. Your learning exercise will begin with you reading about the current situation in the well, usually with a wellbore diagram or other figure providing a visual description of current conditions in the well. You will then read a question and a list of possible answers to the question.
6. Select the answer that you believe is most appropriate or true with the mouse. The white dot to the left of the selected answer will turn black to designate which answer you have selected. If you are satisfied, select the “next” button.
7. You will then see a dialog box indicating whether your answer is correct. Sometimes there will also be information about why it is or is not correct or about what actually happened. It will end with an instruction for what to do next, either return to the previous question and try again to get the correct answer or go on to the next set of conditions and question. When you are finished considering the information in the box, select the “OK” button.
8. This sequence of reaching a decision point (with a description of the conditions in the actual case history at that point in time) and then making your own decision will continue throughout the actual sequence of events. The program will take you from planning the well through ultimately confirming that the underground blowout was successfully controlled.
9. You may wish to have a calculator, pencil, paper, a kill sheet, and/or a data handbook to use while taking the exercise. These can be helpful for calculating volumes and pressures when making decisions about the well control operations. However, no calculations by the student are mandatory to complete the exercise.

10. When you have completed the exercise, or need to stop, simply select the “exit” button. There is no grading or reporting of your answers. The program is strictly for your personal learning.



Appendix C - Simulation Exercise for Reaction to Swabbed-in Kick - Module 3

This appendix contains the instructions and simulation materials for learning about responding to “a small, swabbed-in kick” similar to the one that caused an “Underground Blowout in Deep Gas Well.”

This appendix contains the materials and instructions necessary to conduct the “Simulation Exercise for Reaction to Swabbed-in Kick – Module 3.” This exercise is conducted by one or more students conducting a computer training simulation beginning at the decision point of what do to in reaction to a possible, small, swabbed-in kick. It allows the participating students to consider the circumstances at this key decision point, to draw their own conclusions as to what should be done, to observe how the well reacts to their chosen response, and ultimately to take any well control actions that may be required to control the well. The training module includes this introduction, a simulation snapshot file (in the electronic version of this appendix), instructor notes including a problem description and a summary of problem set up parameters, a set of student instructions, a blank data sheet for student records, and a completed example kill sheet.

Instructor Notes:

An instructor or simulation proctor should review these notes and conduct the simulation himself before conducting a training exercise. Additional preparation can also be gained by reading about the “Underground Blowout in Deep Gas Well” and “Near Miss Due to Small Swabbed Kick” case histories in Chapter 4 of this report and the description of this module in Chapter 6.

The exercise has been constructed as a Drilling Systems DRILLSIM 5, Version 1.66 simulation. The “snapshot,” (Mod3swab.snp) file included in the electronic version of this appendix is used to establish up the initial conditions for the exercise on the simulator. Information on the general well and rig configurations necessary to create a setup file for other training simulators is included in the “problem configuration summary” below. Conducting this simulation on a different simulator requires both creating a basic setup file and then running the simulation, intentionally swabbing in a kick, and then saving the conditions with the kick in the hole as a snapshot file to be used by students in this exercise. Note that tripping out at maximum trip speed for 2 to 3 stands will swab an approximately 3 barrel kick on simulators similar to DRILLSIM5. However, multiple attempts to swab in a migrating gas kick in one other manufacturer’s portable training simulator were unsuccessful. No method was found that would cause the well to be underbalanced for a short period, as due to swabbing, and then allow a quick return to an overbalanced condition with a small kick in the well. Therefore, the only snapshot provided herein is for the DRILLSIM5.

The set of instructions and data sheet for recording trends during the simulation that is included, see the “Student Instructions and Record Sheet,” should be given to the students. A blank kill sheet may also be useful and is included as Appendix F. The training exercise should begin by advising the students that they have just arrived on the rig for a crew change. A trip from TD has just begun and the third stand is being pulled. The floorhand monitoring the continuous-fill trip tank has advised that the hole has taken at least two barrels less mud to fill the hole than calculated. The supervisor they are relieving has just requested that the trip be postponed and the well watched for flow. Request that the students start the simulation and perform the flow check and decide what to do next. They should not be told that the well has kicked. Ideally, they should have the same uncertainty about the meaning of a small volume discrepancy that they would have in a real situation.

There are a number of alternative actions the students might take after observing that there is no flow. Require that they make the decision. You may remind them that their written instructions say “*that MMS regulations state ‘When there is an indication of swabbing or influx of formation fluids, the safety devices and measures necessary to control the well shall be employed. The mud shall be circulated and conditioned, on or near bottom, unless well or mud conditions prevent running the drill pipe back to bottom.’*” Some of the possible reactions are:

1. Assume this is the effect of a slug falling and continue the trip out of the hole,
2. Assume the lack of fillup volume is in fact a kick and shut the well in to begin circulating out on the choke,
3. Attempt to circulate bottoms up with the bit nearly 300 feet above TD,
4. Trip in hole to TD and circulate bottoms up, or
5. Leave the well as-is and watch for any evidence of flow over some set time.

There are additional various reactions that might be taken later as the students observe the results of their decision. In any case, careful observation will eventually demonstrate that a kick has in fact been taken. Student should recognize that when the well is flowing, it should be shut in and a well control procedure implemented. Note that because the drillstring is not filled and there is significant gas in the well, it will take a little time for pressures to stabilize after shut in or after a pump start up.

The major objective of this exercise is to allow the student to reach the conclusions that there is a kick in the well independently of confirmation by the instructor and that when it has been identified, that it can and must be controlled as any other kick.

Three key learnings that should result from running this simulation are:

1. A small kick in an overbalanced well, as from swabbing, is very hard to detect. After the simulation, calculations of hydrostatic pressures in the well can be done to demonstrate why.
2. The critical responsibility when circulating bottoms up to check for a kick or when continuing a trip after an inconclusive kick indication is to keep monitoring kick detection parameters. If a small gas kick is being brought up in a deep well, eventually it is likely to cause enough loss of hydrostatic for the well to begin flowing.
3. The period of time during which the kick can be identified and shut-in safely may only be a few minutes. Failure to react rapidly and appropriately can cause loss of control.

Problem Configuration Summary (as for DRILLSIM5):

Rig Selection

Land Rig with BOP Enabled

Bit Depth: 9990' MD

Defaults for Flow Nipple, Flowline Elevation, Choke Line I.D., Choke Line Friction Factor

Wellbore Geometry

| | | | |
|-------------------------|-------------------------------------|--------------------|--------------|
| Casing: | 9.625" 47# P-110 | Collapse Pressure: | 5610 psi |
| I.D.: | 8.68" | Tensile Strength: | 1,493,000 lb |
| Set At: | 9500' MD & TVD | | |
| Liner: | None (default settings) | Setting Depth: | 0 |
| Tubing: | None (default settings) | Number of Joints: | 0 |
| Upper Drillpipe: | 4.5" 16.6 #/ft | Max Torque: | 30,800 ft-lb |
| Length: | 326 joints | Tensile Strength: | 331,000 lb |
| I.D.: | 3.83" | Cross Sect. Area: | 4.41 sq in |
| Stands Racked: | 30 stands | | |
| Lower Drillpipe: | None (default settings) | Number of Joints: | 0 |
| Heavy Weight Drillpipe: | None (default settings) | Number of Joints: | 0 |
| Drill Collars: | 6.25" OD x 2.00" ID | Wt. per Foot: | 73.43 lb/ft |
| Number of Joints: | 14 drill collars | | |
| Bit Data: | 8.5" diameter | IADC Code: | 134 |
| Time on bit: | 0.15 hrs | Float: | No |
| Nozzles: | 3 – 11's | Bearing: | Sealed |
| Bit Selected: | Fitted | | |
| Hole Data: | Straight Profile | Casing Shoe (MD): | 9500' |
| Liner Shoe (MD): | 0' | Open Hole Size: | 8.5" |
| TD (MD): | 10,014' | TD (TVD): | 10,014' |
| Perforations: | None (use defaults, not applicable) | | |
| Downhole Equipment: | None (use defaults, not applicable) | | |

Formation Data

Geological Summary:

| Number | Type of Zone | Depth at Top (ft) | Strength | Abrasive Factor | Fluid | Permeability (md) | Pressure Gradient (psi/ft) | Pressure at Top (psi) |
|--------|--------------|-------------------|----------|-----------------|-------|-------------------|----------------------------|-----------------------|
| 1 | | 30 | .8 | 1.0 | Gas | 1.0 | .47 | 0 |
| 2 | | 4200 | .8 | 1.0 | Water | 10.0 | .47 | 1939 |
| 3 | | 5600 | 1.0 | 1.0 | Water | 1.0 | .47 | 2590 |
| 4 | | 5602 | 1.25 | 1.0 | Water | 1.0 | .47 | 2591 |
| 5 | | 9500 | 1.0 | 1.0 | Water | 1.0 | 9.75 | 4423 |
| 6 | | 9600 | 1.0 | 1.0 | Water | 1.0 | .56 | 5398 |
| 7 | | 10000 | 2.0 | 1.0 | Water | 1.0 | .56 | 5622 |
| 8 | Reservoir | 10005 | 1.0 | 1.0 | Water | 50.0 | .56 | 5625 |

Casing Shoe Leakoff Gradient .93 psi/ft

Rupture Gradient:

1.12 psi/ft

Propagation Gradient: 1.05 psi/ft Fracture Inhibit: True (no lost returns)
 Hole Drag: .5 lb/ft

Mud System

| | | | | | | |
|--------------------------------------|-----|--------------|------------------------------|---------------|-----|-------------|
| Active Mud System, | PV: | 20 cp | YP: | 12 lb/100sf | MW: | 11.2 lb/gal |
| Pit Capacity: | | 400 bbl | Pit Contents: | | | 350 bbls |
| Water Additions: | | 0 | Settled Solids: | | | .02 bbls |
| Reserve Mud System, | PV: | 21.1 cp | YP: | 12.3 lb/100sf | MW: | 11.5 lb/gal |
| Pit Capacity: | | 400 bbl | Pit Contents: | | | 200 bbls |
| Transfer Pump Rate: | | 0 | | | | |
| Solids Control: | | Use defaults | | | | |
| Mud System Initialization (in well): | | | Reset to initial mud density | | | |
| | PV: | 20 cp | YP: | 12 lb/100sf | MW: | 11.2 lb/gal |

Rig Equipment

| | |
|-----------------------|--|
| Surface BOP: | Use Default Settings |
| Surface Accumulator: | Use Default Settings |
| Mud Pumps #1, 2, &3: | Triplex (all same) |
| Liner size: | 6" Stroke Length: 12" |
| Efficiency: | 95% Rod Diameter: 2.5" (not relevant) |
| Pump Output: | 4.19 gal/stroke (calculated by simulator) |
| Relief Valve Setting: | 3500 psig Relief Valve: Set |
| Max Stroke Rate: | 120 spm |
| Cement Pump: | Use Defaults |
| Power System: | Use Defaults |
| Hoisting System: | Use Defaults |

(If necessary to set up initial conditions for simulation, i.e. to create a new snapshot file, trip out of hole to swab in a 3-barrel kick. Then save a new snapshot file.)

**SIMULATION EXERCISE
 “REACTION TO POSSIBLE SWABBED-IN KICK”
 STUDENT INSTRUCTIONS AND RECORD SHEET**

Objective :

1. Practice precautions, and control if necessary, for kicks taken during trips on the DRILLSIM 5 Version 1.66 simulator.

Simulation Background: A Possible Swabbed-in Kick during a Trip

A bit trip was just begun by the crew you are relieving. They have pulled three stands and noted that the fillup is apparently 2 to 3 barrels less than calculated. This simulation is based conceptually on actual situations that have occurred in deeper wells offshore Texas and Alabama. Most were simply routine measurement problems that occur at the beginning of trips. One ultimately resulted in a major underground blowout.

Specifics: (*file: Mod3swab.snp*)

10,014' MD and TVD, just drilled into objective sand at 10,005' before bit quit.
 10,000 psi BOP stack nipped up and tested to 10,000 psi (as ordered by the operator)
 8.5" bit diameter, 420' of 6.25"x 2.00" drill collars, 4.5" 16.6 #/ft drillpipe
 9.625" 47# P-110 casing set at 9500' with FCCT = 17.9 lb/gal eq (did not leak off)
 Relief valve on pump set at 3500 psi. Returns being taken to trip tank


Follow this Procedure:

- 1) Prepare the pre-recorded data and volume calculations on a kill sheet.
- 2) Start simulation and assess the situation for yourself. Returns are being taken to the trip tank. MMS regulations state “When there is an indication of swabbing or influx of formation fluids, the safety devices and measures necessary to control the well shall be employed. The mud shall be circulated and conditioned, on or near bottom, unless well or mud conditions prevent running the drill pipe back to bottom.” But is this a real indication?
- 3) Take and record (on the kill sheet) slow pump rate pressure before doing anything else. Normal and maximum pump rate is 80 spm. Do not stab an inside BOP or try to strip in hole, neither is necessary.
- 4) Begin whatever action you consider appropriate. Use X10 (this will not make tripping faster, but it will speed up any circulation or migration of fluids. If you intend to continue tripping, it is easiest just to watch what happens versus time, and see if you could make a 10 hour round trip without any problems. If you will need to circulate, remember that you are lined up on the trip tank now. Also do not circulate more than 80 spm.) Watch for kick indicators and take any action that is appropriate. Slow simulator to X1 (REAL TIME) if you need time to keep up with the situation. Note that you really don't need to do any kill calculations to control the well, just to know the slow rate pressure.
- 5) Keep a record of pressures, volumes, and/or bit depth on the attached data sheet to help you detect changes in well conditions.
- 6) Make a “snapshot,” i.e. save a set of well conditions at a particular time, if you encounter a situation or decision point that you may want to return to.
- 7) Your simulation is complete when you have gone at least 8 simulation hours without losing control of the well. If a kill is necessary, complete the kill and verify well is safe by performing a flow check afterwards to complete the simulation.

- 8) **Freeze.** Use “Display,” “Chart Recorder,” and “**Save Data**” to save your data in a text file and record the name below. You will be able to use this data to make a historical plot of what happened during your simulation. **Do not make a snapshot.**

Data File Name: _____

Louisiana State University
Well Control Work Sheet
Surface BOP Stacks
Module 3 - Swab Snap

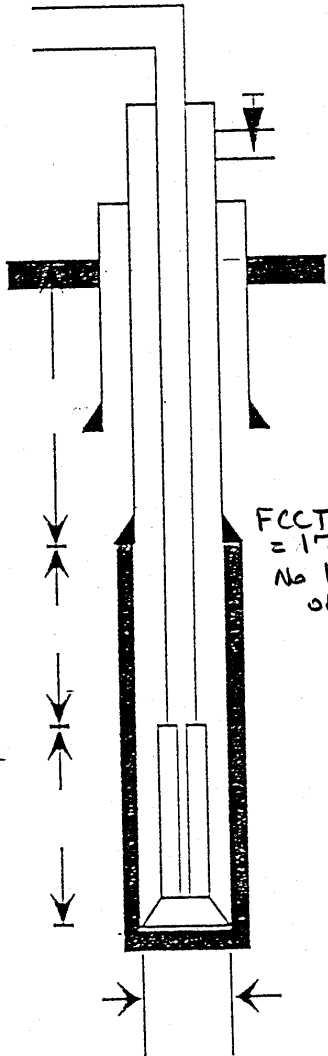


Rev. 2 (1/12/97)

I. PREKICK INFORMATION

A. Casing Data

- 1. Size (Outside Diameter) 9.625 in
 - 2. Grade P-110
 - 3. Weight per Foot 47 lb/ft
 - 4. Casing Depth (Measured) 9500 ft
 - 5. Casing ID (Appendix 1A-2) 8.681 in
 - 6. Burst Pressure (Appendix 1A-2) 9440 psi
 - 7. Maximum Casing Pressure
 - a. Before Casing Burst 6608 psi
(0.7) x (Burst Pressure)
 - b. Before Formation Fracture* 3302 psi
 $[(0.052) \times (\text{Casing Shoe Depth})] \times [(\text{Frac. Grad. in equiv. mud wt.}) - (\text{Mud Wt})]$ MW = 11.2
- * Valid only until kick fluid passes the casing shoe



B. Drill Pipe Data


- 1. Size (Outside Diameter) 4.5 in
- 2. Weight per Foot 16.6 lb/ft
- 3. Capacity Factor (Appendix 1A-3) .0137 bbl/ft

C. Bottom Hole Assembly Data

- 1. Bit Size 8.5 in
- 2. Drill Collars
 - a. Outside Diameter 6.25 in
 - b. Inside Diameter 2.00 in
 - c. Length 420 ft
- 3. Drill Collar Capacity Factor (Appendix 1A-4) .00389 bbl/ft

D. Annulus Capacity Factors (Appendix 1A-4)

- 1. Drill Pipe in Casing (ACF1) .0535 bbl/ft
- 2. Drill Pipe in Open Hole (ACF2) .0505 bbl/ft
- 3. Drill Collars in Open Hole (ACF3) .0322 bbl/ft

| | |
|---|---|
| <p><i>Louisiana State University</i> Well Control Work Sheet Surface BOP Stacks</p> |  |
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E. Pump Data

1. Type: Triplex
2. Liner Size 6 in
3. Stroke Length 12 in
4. Rod Diameter (Double-acting Pumps) — in
5. Pump Factor @ 100% Efficiency (Appendix 1A-5 or 1A-6) .1049 bbl/stroke
6. Pump Factor @ 95 % Efficiency .100 bbl/stroke


F. Circulating Pressures

1. Date 3/20/99
2. Time 4:00 pm
3. Measured Depth 10,014 ft
4. Mud Weight 11.2 ppg
5. Circulating Pressure at Normal Rate
 $P_N = 2780$ psi @ 80 strokes/min
6. Circulating Pressure at Reduced (Kill) Rate (SCR)
 $P_{SCR} = 735$ psi @ 40 strokes/min

II. KICK INFORMATION

- (after kick detected while circulating bottoms up.)
- A. Date 3/20/99
 - B. Time 6:14 pm
 - C. Depths
 1. Measured Depth (for volume calculations) 10,014 ft
 2. True Vertical Depth (for pressure calculations) 10,014 ft
 - D. Stabilized Shut-In Pressures
 1. Casing (SICP) 73 psi
 2. Drill Pipe (SIDPP) 0 psi
 - E. Pit Gain 17 bbl
 - F. Present Mud Weight 11.2 ppg

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III. CALCULATIONS

A. Kill Weight Mud

1. Increase in Mud Weight 0 ppg
(SIDPP) ÷ (0.052) ÷ (TVD)
2. Kill Weight Mud 11.2 ppg
(Present Mud Wt.) + (Increase in Mud Wt.)

B. Mud Volume in Active System

1. Mud Volume in Active Pits 367 bbl] Surface Volume
(Active Surface Volume)
2. Mud Volume in Drill Pipe 131.4 bbl] Mud Volume
(Drill Pipe Length) x (DP Capacity Factor)
3. Mud Volume in Drill Collars 1.6 bbl] 133 bbl
(Drill Collar Length) x (DC Capacity Factor)
4. Mud Volume in Drill Pipe-Casing Annulus 508.3 bbl]
5. Mud Volume in Drill Pipe-Open Hole Annulus 4.7 bbl] Mud Volume
(Length of Drill Pipe in Open Hole) x (ACF2)
6. Mud Volume in Drill Collar-Open Hole Annulus 13.5 bbl] 526.5 bbl
(Length of Drill Collars in Open Hole) x (ACF3)
7. Total Mud Volume in Active System 1026.5 bbl

C. Barite Necessary to Weight Up Active System

1. Sacks of Barite Required per 100-bbl (Appen. 1A-7) 0 sacks/100-bbl
(((1099) x (Increase in Mud Weight)) ÷ [(28.35) - (Kill Weight Mud)])
2. Total 100-lb Sacks Required 0 sacks
[(Total Mud Volume in Active System) ÷ 100] x (Sacks Required per 100-bbl)
3. Total Mud Volume Increase 0 bbl
(0.091) x (Total Sacks of Barite Required)

D. Determination of Pump Strokes

1. Mud Volume in Drill String 133 bbl
2. Pump Strokes (Surface to Bit) 1330 strokes
(Mud Volume in Drill String) ÷ (Pump Factor)
3. Mud Volume in Annulus 526.5 bbl
4. Pump Strokes (Bit to Surface) 5265 strokes
5. Total Strokes to Circulate Well 6595 strokes

Appendix D - Simulation Exercise for a Kick Taken with Low Kick Tolerance - Module 4

This appendix contains the instructions and the simulation materials for learning about responding to a kick taken while drilling with a low kick tolerance.

This appendix contains the materials and instructions necessary to conduct the “Simulation Exercise for a Kick Taken with Low Kick Tolerance.” This exercise is based on the case history of a “Kick Taken While Drilling with Low Kick Tolerance.” It is conducted by one or more students running a computer training simulation beginning either before drilling into the kick or after shutting in on a kick that was large enough to initiate lost returns.

The instructions herein are focused on the students running the case where they drill into and must detect the kick themselves. The simulation gives students the opportunity to decide what to do in reaction to possible lost returns during a well control operation, to observe how the well reacts to their chosen response, and ultimately to take any well control actions that may be required to control the well. The training module includes this introduction, two simulation snapshot files (in the electronic version of this appendix), instructor notes including a problem description and a summary of problem set up parameters, a set of student instructions including questions and problems, a blank data sheet for student records, and a completed example kill sheet.

Instructor Notes:

An instructor or simulation proctor should review these notes and conduct the simulation himself before conducting a training exercise. Additional preparation can also be gained by reading about the “Kick Taken While Drilling with Low Kick Tolerance” case history in Chapter 4 of this report and the description of this module in Chapter 6.

This near miss case history was chosen specifically to provide opportunities to avoid an underground blowout by either rapid and careful implementation of conventional kill methods or by applying basic hydraulic calculations to “non-conventional” kill methods. The drill string being near bottom in this case means that drillpipe pressure can be used as an indicator of bottomhole pressure as in conventional well control. Consequently, drillpipe pressure indicating a bottomhole pressure greater than that measured at initial shut-in conditions can be used to indicate that the kick formation is being controlled, even for non-routine methods. Practice preparing a conventional kill sheet is part of the exercise and is helpful for determining the drillpipe pressure and volumes to be pumped even for non-routine methods. A blank kill sheet is included as Appendix F.

Begin the exercise by advising participants that they are drilling a moderately deep well that is approaching a liner point in a transition zone below intermediate casing. Hand out the student instructions included in this appendix. Ask them to use the snapshot file entitled “Mod4KT.snp.” This simulation is based on an actual kick taken

offshore Louisiana while drilling with a 16.2 ppg mud and a 16.9 ppg measured leak off test at the intermediate casing shoe.

After drilling into the kick zone and shutting in the well, ask the participants to consider the following alternative responses if returns were lost after shutting the well in. An alternative is to have them run the simulation based on the snapshot file “Mod4KTsi.snp,” where lost returns have already begun to occur.

1. Driller’s method,
2. Wait and weight method,
3. Bullhead down drillpipe,
4. Bullhead down casing,
5. Bullheading combined with subsequent circulation on choke,
6. Bullheading drillpipe and casing simultaneously, a “sandwich” kill,
7. Low choke pressure method, or
8. Volumetric control.

Once they begin simulating, remind them that they can always shut back in and check static pressures to get a simpler view of what is happening in the well and to slow down any possibility that they are losing control. When they have completed the simulation, ask them about whether they were successful and why. Verify that they have answered the questions included in the student instructions.

These simulations are intended to give participants the opportunity to think downhole, to diagnose problems, and to develop, implement, and learn from special approaches to well control with threatened or actual lost returns. The simulations can be used to reinforce the importance of rapid detection, to see how having on-bottom circulation allows adaptation of conventional kill methods to a kick with induced lost returns, or to practice the procedural steps and see expected results of non-conventional well control methods. Instructors are encouraged to evaluate and use this case history-based simulation for other training purposes relating to the situation of drilling with a low kick tolerance.

Problem Configuration Summary (as for DRILLSIM5 file "Mod3KT.snp"):

Rig Selection

Land Rig with BOP Enabled

Bit Depth: 11,610' MD

Defaults for Flow Nipple, Flowline Elevation, Choke Line I.D., Choke Line Friction Factor

Wellbore Geometry

Casing: 10.875" 51# P-110 Collapse Pressure: 3660 psi
 I.D.: 9.90" Tensile Strength: 1,1594,000 lb
 Set At: 9,850' MD & TVD
 Liner: None (default settings) Setting Depth: 0
 Tubing: None (default settings) Number of Joints: 0
 Upper Drillpipe: 5.0" 19.66 #/ft Max Torque: 30,000 ft-lb
 Length: 1200 joints Tensile Strength: 561,000 lb
 I.D.: 4.28" Cross Sect. Area: 5.28 sq in
 Stands Racked: 3 stands
 Lower Drillpipe: None (default settings) Number of Joints: 0
 Heavy Weight Drillpipe: 5.0" 49.3 #/ft Length: 20 joints Tensile
 Strength: 691,000 lb I.D.: 3.0"
 Drill Collars: 7.25" OD x 3.00" ID Wt. per Foot: 83 lb/ft
 Number of Joints: 10 drill collars
 Bit Data: 9.875" diameter IADC Code: 134
 Time on bit: 0.03 hrs Float: No
 Nozzles: 1 - 18, 2 - 13's Bearing: Sealed
 Bit Selected: Fitted
 (Note: actual well used 10.625" bit inside 11.75" casing, but this bit size is not available in DRILLSIM5, so the next nearest bit size and corresponding casing was chosen.)
 Hole Data: Straight Profile Casing Shoe (MD): 9850'
 Liner Shoe (MD): 0' Open Hole Size: 9.88"
 TD (MD): 11,635' TD (TVD): 11,635'
 Perforations: None (use defaults, not applicable)
 Downhole Equipment: None (use defaults, not applicable)

Formation Data

Geological Summary:

| Number | Type of Zone | Depth at Top (ft) | Strength | Abrasive Factor | Fluid | Permeability (md) | Pressure Gradient (psi/ft) | Pressure at Top (psi) |
|--------|--------------|-------------------|----------|-----------------|-------|-------------------|----------------------------|-----------------------|
| 1 | | 30 | .8 | 1.0 | Water | 1.0 | .47 | 0 |
| 2 | | 400 | .5 | 0.1 | Water | 10.0 | .47 | 172 |
| 3 | | 9850 | 1.0 | 1.0 | Water | 1.0 | 3.17 | 4566 |
| 4 | | 11500 | 1.0 | 1.0 | Water | 1.0 | 2.26 | 9797 |
| 5 | Reservoir | 11639 | .5 | 1.0 | Gas | 1.0 | .15 | 10111 |
| 6 | | 11700 | 1.5 | 1.0 | Water | 1.0 | .87 | 10120 |
| 7 | | 15000 | 1.0 | 1.0 | Water | 1.0 | .65 | 12991 |
| 8 | | 15001 | 2.5 | 1.0 | Water | 1.0 | .65 | 12992 |

Casing Shoe Leakoff Gradient: .88 psi/ft Rupture Gradient: .90 psi/ft
 Propagation Gradient: .89 psi/ft Fracture Inhibit: False (can lose returns)

Hole Drag: 0 lb/ft

Mud System

| | | | | | | |
|--------------------------------------|-----|--------------|------------------------------|--------------|----------|-------------|
| Active Mud System, | PV: | 26 cp | YP: | 8 lb/100sf | MW: | 16.2 lb/gal |
| Pit Capacity: | | 400 bbl | Pit Contents: | | 252 bbls | |
| Water Additions: | | 0 | Settled Solids: | | .02 bbls | |
| Reserve Mud System, | PV: | 28 cp | YP: | 8.4 lb/100sf | MW: | 17.0 lb/gal |
| Pit Capacity: | | 400 bbl | Pit Contents: | | 200 bbls | |
| Transfer Pump Rate: | | 0 | | | | |
| Solids Control: | | Use defaults | | | | |
| Mud System Initialization (in well): | | | Reset to initial mud density | | | |
| | PV: | 26 cp | YP: | 8 lb/100sf | MW: | 16.2 lb/gal |

Rig Equipment

| | | | |
|-----------------------|---|----------------|---------------------|
| Surface BOP: | Use Default Settings | | |
| Surface Accumulator: | Use Default Settings | | |
| Mud Pumps #1 & 2: | Triplex (both same) | | |
| Liner size: | 5.5" | Stroke Length: | 12" |
| Efficiency: | 95% | Rod Diameter: | 2.5" (not relevant) |
| Pump Output: | 3.52 gal/stroke (calculated by simulator) | | |
| Relief Valve Setting: | 3900 psig | Relief Valve: | Set |
| Max Stroke Rate: | 120 spm | | |
| Mud Pumps #3: | Triplex | | |
| Liner size: | 6" | Stroke Length: | 12" |
| Efficiency: | 95% | Rod Diameter: | 2.5" (not relevant) |
| Pump Output: | 4.19 gal/stroke (calculated by simulator) | | |
| Relief Valve Setting: | 3500 psig | Relief Valve: | Set |
| Max Stroke Rate: | 120 spm | | |
| Cement Pump: | Use Defaults | | |
| Power System: | Use Defaults | | |
| Hoisting System: | Use Defaults | | |

(Note: Snapshot file "Mod3KTsi.snp" is based on these same settings, but it was saved after drilling to 11,641', taking an 11 barrel kick, and shutting in the well. This caused lost returns as pressures built up after shut-in.)

SIMULATION EXERCISE
“KICK TAKEN WHILE DRILLING WITH LOW KICK TOLERANCE”
STUDENT INSTRUCTIONS AND RECORD SHEET

Objectives:

1. Practice kick identification, flow check, shut-in, pump start up, and kick removal on the DRILLSIM 5 Version 1.66 simulator for a situation with small kick margin.
2. Experiment with “non-conventional” control methods if necessary using the simulator. Apply basic concepts to non-standard situation.
3. Practice volume calculations on kill sheet.

Problem Set: ***Kill Sheet Volume Calculations and Contingency Planning***

- 1) Complete all pre-recorded calculations (except slow circulating rate pressures) and all volume calculations (assuming actual TD is approximately 11,640') on a kill sheet.
- 2) Consider the “Options” listed on the next page as alternative responses to losing returns after you shut the well in. Choose the option that you consider most likely to succeed and write a short explanation of why you think it is best in the space below.

Simulation Background: ***Detection and Control of Kick Taken While Drilling***

You are drilling a moderately deep well that is approaching a liner point in a transition zone below intermediate casing. This simulation is based on an actual kick taken offshore Louisiana while drilling with a 16.2 ppg mud and a 16.9 ppg measured leak off test at the intermediate casing shoe. The SICP increased to 3160 psig over 9 hours while mixing kill weight mud after the actual kick. “Non-conventional” well control methods were used to successfully control the well. This is an opportunity for you to do better, or to show that you can also recover from a threatened underground blowout.

Specifics: (***file: Mod4KT.snp***)

11,635' MD and TVD well in transition zone (i.e. mud weight has been increasing)
 10,000 psi BOP stack nipped up and tested to 10,000 psi (as ordered by the operator)
 Currently drilling with 16.2 ppg water based mud
 9.875" bit diameter, 300' of 7.25" x 3.00" drill collars, 5" 19.5 #/ft drillpipe
 10.75" 51# P-110 casing set at 9850' with LOT = 16.9 lb/gal eq
 Relief valve on pump set at 3900 psi.


Procedure:

- 1) Complete the pre-recorded data on a kill sheet to match the well conditions in your simulation.
- 2) Take and record (on the kill sheet) slow pump rate pressures at two rates, the lowest should be 20 spm and the other should be about 68 spm.
- 3) Record the time, depth, standpipe pressure, mud weight and pit level on the kill sheet and data sheet before you begin drilling.
- 4) Lower drill string to TD and begin drilling with about 68 spm on each of two pumps, Increase simulation speed to X10 and drill to 11,638'. Watch for kick indicators.

- 5) Slow simulator to X1 and monitor ROP for a drilling break.
- 6) Implement the flow check procedure when you are 2' into the drilling break or if you get a strong indication of a kick, such as a significant pit gain. Watch for flow carefully, if necessary go briefly to X10 to be sure you have watched long enough.
- 7) Perform a hard shut-in if the flow check is positive.
- 8) Measure and record the required kick information on the kill sheet. Freeze and save a snapshot of your simulation, but do not load the new snapshot.
- 9) Keep a record of pressures and volumes on the attached data sheet. Think about what the fluctuations in drillpipe and casing pressure mean before taking action.
- 10) Talk with your partners and instructors, about actions that might be appropriate. Consider the following options:
 - Driller's method
 - Wait and weight method
 - Bullhead down drillpipe
 - Bullhead down casing
 - Bullheading down casing followed with subsequent circulation on choke
 - Bullheading drillpipe and casing simultaneously ("sandwich" kill)
 - Low choke pressure method
 - Volumetric control
- 11) Consider your options within a given method.
 - What mud weight to use?
 - What pump rate and pressure?
 - When to start?
- 12) Unfreeze (run) and continue simulating. Take any action you consider appropriate. Remember that you can always shut back in and check static pressures to get an idea of how you are doing and to slow things down.
- 13) Complete the kill and verify well is safe by performing a flow check.
- 14) **Freeze.** Use "Display," "Chart Recorder," and "**Save Data**" to save your data in a text file and record the file name below. This file will allow you to plot a history of pressures and pit volume versus time. **Do not make a snapshot.**

Data File Name: _____

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Well Control Work Sheet
Surface BOP Stacks

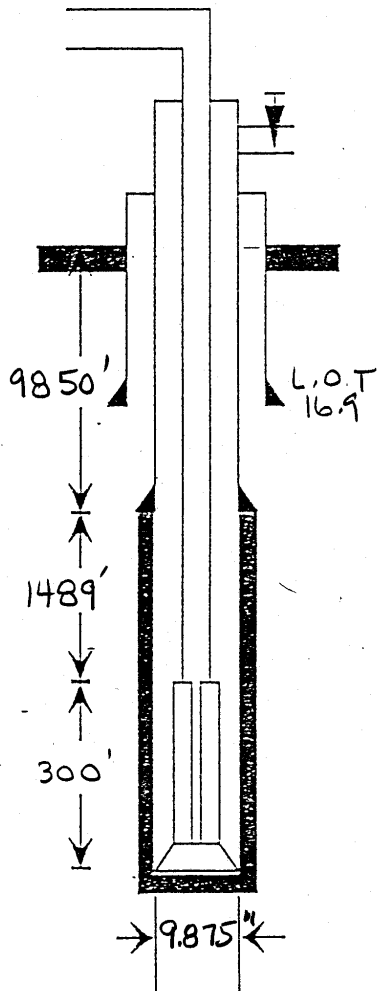


Rev. 2 (1/12/97) Mod 3 KT .snp

I. PREKICK INFORMATION

A. Casing Data

- | | |
|--|-------------------|
| 1. Size (Outside Diameter) | <u>10 7/8</u> in |
| 2. Grade | <u>P-110</u> |
| 3. Weight per Foot | <u>~ 51</u> lb/ft |
| 4. Casing Depth (Measured) | <u>9850</u> ft |
| 5. Casing ID (Appendix 1A-2) | <u>~ 9.876</u> in |
| 6. Burst Pressure (Appendix 1A-2) | <u>~ 8060</u> psi |
| 7. Maximum Casing Pressure | |
| a. Before Casing Burst (0.7) x (Burst Pressure) | <u>5642</u> psi |
| b. Before Formation Fracture* [(0.052) x (Casing Shoe Depth)] x [(Frac. Grad. in equiv. mud wt.) - (Mud Wt)] | <u>358</u> psi |
| | <u>MW = 16.2</u> |
- * Valid only until kick fluid passes the casing shoe..



B. Drill Pipe Data

- | | |
|------------------------------------|----------------------|
| 1. Size (Outside Diameter) | <u>5</u> in |
| 2. Weight per Foot | <u>19.5</u> lb/ft |
| 3. Capacity Factor (Appendix 1A-3) | <u>.01776</u> bbl/ft |


C. Bottom Hole Assembly Data

- | | |
|--|----------------------|
| 1. Bit Size | <u>9 7/8</u> in |
| 2. Drill Collars | |
| a. Outside Diameter | <u>7.25</u> in |
| b. Inside Diameter | <u>3.00</u> in |
| c. Length | <u>300</u> ft |
| 3. Drill Collar Capacity Factor (Appendix 1A-4) | <u>.00874</u> bbl/ft |

D. Annulus Capacity Factors (Appendix 1A-4)

- | | |
|--------------------------------------|---------------------|
| 1. Drill Pipe in Casing (ACF1) | <u>.0705</u> bbl/ft |
| 2. Drill Pipe in Open Hole (ACF2) | <u>.0704</u> bbl/ft |
| 3. Drill Collars in Open Hole (ACF3) | <u>.0437</u> bbl/ft |

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Well Control Work Sheet
Surface BOP Stacks



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E. Pump Data


- 1. Type: Triplex
- 2. Liner Size 5.5 in
- 3. Stroke Length 12.0 in
- 4. Rod Diameter (Double-acting Pumps) in
- 5. Pump Factor @ 100% Efficiency (Appendix 1A-5 or 1A-6) 0.088 bbl/stroke
- 6. Pump Factor @ 95 % Efficiency 0.084 bbl/stroke

F. Circulating Pressures

- 1. Date 2/27/00
- 2. Time 1:45 pm
- 3. Measured Depth 11,635 ft
- 4. Mud Weight 16.2 ppg
- 5. Circulating Pressure at Normal Rate
 $P_N = 3011$ psi @ 136 strokes/min
- 6. Circulating Pressure at Reduced (Kill) Rate (SCR)
 $P_{SCR} = 787$ psi @ 68 strokes/min

II. KICK INFORMATION

- A. Date 2/27/00
- B. Time 2:00 pm
- C. Depths
 - 1. Measured Depth (for volume calculations) 11,639 + ft
 - 2. True Vertical Depth (for pressure calculations) 11,639 + ft
- D. Stabilized Shut-In Pressures
 - 1. Casing (SICP) 333 psi
 - 2. Drill Pipe (SIDPP) 319 psi
- E. Pit Gain ~1 bbl
- F. Present Mud Weight 16.2 ppg

| | |
|---|---|
| <p><i>Louisiana State University</i> <i>Well Control Work Sheet</i> <i>Surface BOP Stacks</i></p> |  |
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III. CALCULATIONS

A. Kill Weight Mud

1. Increase in Mud Weight .53 → .6 ppg
(SIDPP) ÷ (0.052) ÷ (TVD)
2. Kill Weight Mud 16.8 ppg
(Present Mud Wt.) + (Increase in Mud Wt.)

B. Mud Volume in Active System


1. Mud Volume in Active Pits 251 bbl] Surface Volume
(Active Surface Volume)
2. Mud Volume in Drill Pipe 201.4 bbl] Mud Volume
(Drill Pipe Length) x (DP Capacity Factor)
3. Mud Volume in Drill Collars 2.6 bbl] 204 bbl
(Drill Collar Length) x (DC Capacity Factor)
4. Mud Volume in Drill Pipe-Casing Annulus 694.4 bbl]
(Length of Drill Pipe in Casing) x (ACF1)
5. Mud Volume in Drill Pipe-Open Hole Annulus 104.8 bbl] Mud Volume
(Length of Drill Pipe in Open Hole) x (ACF2)
6. Mud Volume in Drill Collar-Open Hole Annulus 13.1 bbl] 812 bbl
(Length of Drill Collars in Open Hole) x (ACF3)
7. Total Mud Volume in Active System 1267 bbl

C. Barite Necessary to Weight Up Active System

1. Sacks of Barite Required per 100-bbl (Appen. 1A-7) 57.1 sacks/100-bbl
(((1099) x (Increase in Mud Weight)) ÷ [(28.35) - (Kill Weight Mud)])
2. Total 100-lb Sacks Required 723 sacks
[(Total Mud Volume in Active System) ÷ 100] x (Sacks Required per 100-bbl)
3. Total Mud Volume Increase 66 bbl
(0.091) x (Total Sacks of Barite Required)

D. Determination of Pump Strokes

1. Mud Volume in Drill String 204 bbl
2. Pump Strokes (Surface to Bit) 2429 strokes
(Mud Volume in Drill String) ÷ (Pump Factor)
3. Mud Volume in Annulus 812 bbl
4. Pump Strokes (Bit to Surface) 9667 strokes
5. Total Strokes to Circulate Well 12,096 strokes


Louisiana State University
Well Control Work Sheet
Surface BOP Stacks

Rev. 2 (1/12/07)

I. Pre-Kick Information

- A. Maximum Allowable Surface Pressure 5642 psi
- B. Present Mud Weight 16.2 ppg
- C. Kill Rate (SCR) 68 spm
- C. Circulating Pressure at Kill Rate (P_{SCR}) 787 psi

II. Kick Information

- A. Shut-In Drill Pipe Pressure (SIDPP) 319 psi
- B. Shut-In Casing Pressure (SICP) 333 psi
- C. Measured Depth 11639 ft
- D. True Vertical Depth 11639 ft
- E. Pit Gain 1 bbls
- F. Kill Weight Mud 16.8 ppg

III. Mud Volumes, Barite Requirements, & Pump Strokes

- A. Total Mud Volume in Active System 1267 bbls
- B. Barite Required to Weight Up System 723 sks
- C. Mud Volume Increase due to Weight-Up 66 bbls
- D. Pump Strokes, Surface to Bit 2429 sks
- E. Pump Strokes, Bit to Surface 9667 sks
- F. Total Strokes to Circulate Well 12096 sks

IV. Calculations

- A. Initial Circulating DP Pressure @ Kill Rate (P_{SCR}) + (SIDPP) 1106 psi
- B. Final Circulating DP Pressure @ Kill Rate (P_{SCR}) x (Kill Wt Mud) + (Present Mud Wt) 816 psi
- C. Total DP Pressure Reduction (A) - (B) 290 psi
- D. Pressure Drop per Step 50 psi
- E. Pump Strokes per Step [(Surface to Bit Pump Stks) + (C)] x (D) 419 stks

V. Drill Pipe Pressure Schedule

| Strokes Pumped | DP Pressure |
|----------------|-------------|
| 0 | 1106 |
| 419 | 1056 |
| 838 | 1006 |
| 1257 | 956 |
| 1676 | 906 |
| 2095 | 856 |
| 2429 | 816 |
| | |
| | |
| | |
| | |
| | |
| | |
| | |



Appendix E - Simulation Exercises for Deep Underground Blowout - Module 5

This appendix contains partially completed materials for possible training exercises to simulate the dynamic kill of an underground blowout in a deep gas well.

This appendix contains several snapshot files for possible use in simulations to practice both control of swabbed-in kicks and dynamic kills on a deep underground blowout. These files were created to run simulations on the Drilling Systems (UK) Limited DRILLSIM5 Version 1.66 training simulator. Given the difficulty of creating these files and the similar or greater difficulty to duplicate them on other training simulators, this module was left incomplete when the project was revised to include four modules instead of five.

The files included in the electronic version of this report are listed below. Each is intended to represent a decision point in the actual case history of an “Underground Blowout in Deep Gas Well.”

| <u>Snapshot File Name</u> | <u>Description of File</u> |
|---------------------------|--|
| ugbo-d1.snp | Flow check of swabbed-in gas kick in deep gas well during trip in hole at 18,400'. Slight, trickling flow due to migration and expansion of gas. Simulation shows difficulty of detection. Pit gain over previous 20+ hours was less than 15 barrels. Requires additional expansion before observing significant flow. [Decision point #1] |
| ugbo-d2.snp | Shut-in on swabbed-in gas kick in deep gas well during trip in hole at 18,400'. SIDP = 0 psig and SICP = 100 psig. Pit gain = 20 barrels. Simulation showed well is easy to control at this point using driller's method. [Decision point #2] |
| ugbo-d3.snp | Positive flow check of deep gas well during trip in hole at 19,300'. Pit gain of 73 barrels. Well flowing about 20 bpm in simulation, but SICP only about 200 psi. Achieved kill after circulating 18,653 strokes of 12.5 ppg mud on choke keeping equivalent SIDP above 780 psi, lost 100 bbl of mud during kill. [Decision point #3] |
| ugbo-d4.snp | Underground blowout in progress after stripping in hole to 20,500' in deep gas well. SIDP = 1190 psig and SICP = 4170 psig. [Decision point #4] |
| ugbo-dk.snp | Well set up to initiate dynamic kill of underground blowout in deep gas well with 13.5 ppg mud by pumping down drillpipe and annulus simultaneously with bit at 20,502 feet. SIDP = 0 and SICP = 2529 psig. Simulation showed successful kill using method applied in actual case history, but pressures do not match because of difficulty matching initial conditions exactly. [Dynamic kill initiation point] |



Appendix F - Surface Kill Sheet

This appendix contains a blank LSU surface kill sheet.

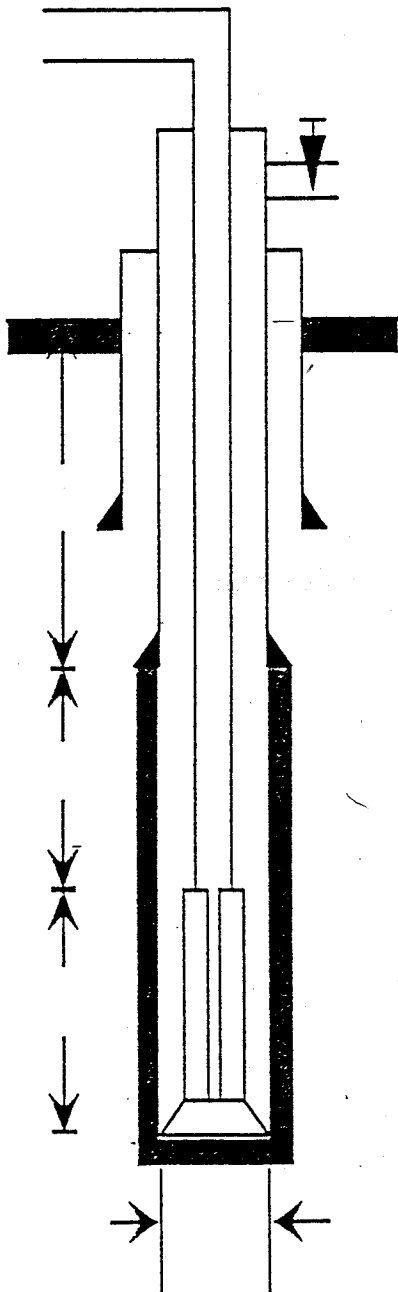


I. PREKICK INFORMATION

A. Casing Data

1. Size (Outside Diameter) _____ in
 2. Grade _____
 3. Weight per Foot _____ lb/ft
 4. Casing Depth (Measured) _____ ft
 5. Casing ID (Appendix 1A-2) _____ in
 6. Burst Pressure (Appendix 1A-2) _____ psi
 7. Maximum Casing Pressure
 - a. Before Casing Burst _____ psi
(0.7) x (Burst Pressure)
 - b. Before Formation Fracture* _____ psi

$$[(0.052) \times (\text{Casing Shoe Depth})] \times [(\text{Frac. Grad.in equiv. mud wt.}) - (\text{Mud Wt})]$$
- * Valid only until kick fluid passes the casing shoe



B. Drill Pipe Data

1. Size (Outside Diameter) _____ in
2. Weight per Foot _____ lb/ft
3. Capacity Factor (Appendix 1A-3) _____ bbl/ft

C. Bottom Hole Assembly Data

1. Bit Size _____ in
2. Drill Collars
 - a. Outside Diameter _____ in
 - b. Inside Diameter _____ in
 - c. Length _____ ft
3. Drill Collar Capacity Factor (Appendix 1A-4) _____ bbl/ft

D. Annulus Capacity Factors (Appendix 1A-4)

1. Drill Pipe in Casing (ACF1) _____ bbl/ft
2. Drill Pipe in Open Hole (ACF2) _____ bbl/ft
3. Drill Collars in Open Hole (ACF3) _____ bbl/ft

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E. Pump Data

1. Type: _____
2. Liner Size _____ in
3. Stroke Length _____ in
4. Rod Diameter (Double-acting Pumps) _____ in
5. Pump Factor @ 100% Efficiency _____ bbl/stroke
(Appendix 1A-5 or 1A-6)
6. Pump Factor @ _____ % Efficiency _____ bbl/stroke

F. Circulating Pressures

1. Date _____
2. Time _____
3. Measured Depth _____ ft
4. Mud Weight _____ ppg
5. Circulating Pressure at Normal Rate
 $P_N =$ _____ psi @ _____ strokes/min
6. Circulating Pressure at Reduced (Kill) Rate (SCR)
 $P_{SCR} =$ _____ psi @ _____ strokes/min

II. KICK INFORMATION

- A. Date _____
- B. Time _____
- C. Depths
 1. Measured Depth (for volume calculations) _____ ft
 2. True Vertical Depth (for pressure calculations) _____ ft
- D. Stabilized Shut-In Pressures
 1. Casing (SICP) _____ psi
 2. Drill Pipe (SIDPP) _____ psi
- E. Pit Gain _____ bbl
- F. Present Mud Weight _____ ppg

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III. CALCULATIONS

A. Kill Weight Mud

1. Increase in Mud Weight _____ ppg
 (SIDPP) ÷ (0.052) ÷ (TVD)
2. Kill Weight Mud _____ ppg
 (Present Mud Wt.) + (Increase in Mud Wt.)

B. Mud Volume in Active System

1. Mud Volume in Active Pits _____ bbl } Surface Volume
 (Active Surface Volume)
2. Mud Volume in Drill Pipe _____ bbl } Mud Volume
 (Drill Pipe Length) x (DP Capacity Factor) } in Drill String
3. Mud Volume in Drill Collars _____ bbl } _____ bbl
 (Drill Collar Length) x (DC Capacity Factor)
4. Mud Volume in Drill Pipe-Casing Annulus _____ bbl } Mud Volume
 (Length of Drill Pipe in Casing) x (ACF1) } in Annulus
5. Mud Volume in Drill Pipe-Open Hole Annulus _____ bbl } _____ bbl
 (Length of Drill Pipe in Open Hole) x (ACF2)
6. Mud Volume in Drill Collar-Open Hole Annulus _____ bbl } _____ bbl
 (Length of Drill Collars in Open Hole) x (ACF3)
7. Total Mud Volume in Active System _____ bbl

C. Barite Necessary to Weight Up Active System

1. Sacks of Barite Required per 100-bbl (Appen. 1A-7) _____ sacks/100-bbl
 $[(1099) \times (\text{Increase in Mud Weight})] \div [(28.35) - (\text{Kill Weight Mud})]$
2. Total 100-lb Sacks Required _____ sacks
 $[(\text{Total Mud Volume in Active System}) \div 100] \times (\text{Sacks Required per 100-bbl})$
3. Total Mud Volume Increase _____ bbl
 (0.091) x (Total Sacks of Barite Required)

D. Determination of Pump Strokes

1. Mud Volume in Drill String _____ bbl
2. Pump Strokes (Surface to Bit) _____ strokes
 (Mud Volume in Drill String) ÷ (Pump Factor)
3. Mud Volume in Annulus _____ bbl
4. Pump Strokes (Bit to Surface) _____ strokes
5. Total Strokes to Circulate Well _____ strokes

