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DRILLING THROUGH SHALLOW GAS ZONES IN HUNGARY

The prospecting activity for CH is more than 60 years old in Hungary. During this long time we had 73 documented blowouts and more undocumented kicks. Well control was difficult and expensive here because of the abnormally high temperatures and the extreme overpressures of the formations. Among the blowouts we had 12 oil and gas, 1 steam with 180 C° surface temperature, 4 CO^2 blowouts with -30 C° surface temperature. 15 rigs were destroyed, 10 craters were formed by the blowouts and, unfortunately, a thrown DC killed one toolpusher.

Shallow gas blowouts are perhaps the most difficult well control problem. A shallow gas blowout on a rig can cause large financial losses. For example, a blowout resulted in the total loss of a rig in Hungary. This event created a fishing lake near to Hajdúszoboszló. Studying the previous blowouts is very important for the drillers, engineers and instructors so as to prevent any well control problems. The results, observations and conclusions help to change the practice and technology in order to avoid any risk situations during normal drilling operations.

By the favorable results of the skilled, well-trained drillers, better and better tools and equipment, day by day practical experience, and the special Well Control Training School, we have had only one blowout in the last 10 years.

This paper reviews shallow gas blowouts while drilling in Hungary and discusses current industry myths about shallow gas, typical results from a shallow gas blowout that affect the kill operation, kill options, selection criteria and well killing guidelines. The objectives of this case study are to describe procedures which will reduce the risk and cost of controlling the flow if a blowout occurs and build the experiences into our training programs to prevent this accident.

Conclusion of this study include the recommended well control procedures and the required well control equipment for Hajduszoboszlo field.

INTRODUCTION

Shallow gas blowouts, as a general class, are the most difficult type of blowout to kill. Two useful definitions can be given to shallow gas. The first is gas encountered at shallow depths for which the fracture gradients are low and do not allow kicks to be controlled with conventional shut-in techniques. These depths range from initial soil penetration own to the casing setting point for either conductor or surface casing. Recent cases showed large blowouts occurring from a zone even at 400-1000 ft subsurface on a land blowout.

Another common type-of shallow gas blowout includes those blowouts occurring in open hole below conductor or surface casing. The flow cannot be closed-in and killed with conventional techniques. A key parameter in shallow blowouts is the small tolerances between formation pressure overbalance with the drilling mud and the rock integrity (fracture gradient). The low fracture gradient is the focal point of the issue.

The pressure overbalance is small as compared to situations in deeper drilling environments. Due to the low overbalance margins, relatively moderate amounts of swabbing or core volume gas cutting can initiate gas flows that result in blowouts.

Land blowouts resulting from shallow gas are a recognized problem by drilling industry and well control specialists in Hungary. But blowouts had different characteristics for each situation that required a case-by-case analysis to develop the most appropriate control techniques. Control techniques will be described in this paper. Primary control techniques are those are implemented with existing equipment and systems generally found on drilling rig. These are usually performed by the rig crew at the time of the blowout. Remedial techniques are defined as those procedures that are the generally performed by blowout specialists with special techniques and equipment.

Although the literature of petroleum engineering gives occasional reports on the events of infamous blowouts or fires in oil or gas wells, the accounts are most detailed on the technical solutions of well capping, fire extinguishing and well killing. Publications summarizing the blowouts in the course of drilling or petroleum production activity of a drilling company or a country or analyzing the actual causes of their development are much less frequently published.

The most important reasons for that are that a detailed account of accidents that can be led back mostly to human omissions do not put any drilling company into favorable light and that some subjective judgment is almost inevitable in the assessment of personal responsibility when investigating the causes.

However, it is necessary for forming an objective technical opinion that companies involved in petroleum drilling and production should perform an honest and objective investigation of their own activities and face the events of the major blowouts in their operational field, the statistical summary of the origins of the blowouts and to draw the conclusions from the events, as well as to focus attention on the conditions and circumstances playing major roles in blowout prevention.

The geological conditions of the Carpathian Basin have revealed a number of remarkable features, the most characteristic of which are primarily a significant overpressure of certain formations, temperature conditions differing considerably from the global average, and the formation fracturing pressure irregularities [1].

From the point of drilling technology and well control, the Hajdúszoboszló field is an especially interesting area. It has been explored as a result of a search for a gravitation maximum, which led to the exploitation of a gas field of medium capacity. After exploitation, the formation was completed for the purpose of underground gas storage.

It is a special tectonic feature of the geological formation that in the upper section of the sequence of strata the least principal stress is horizontal in East-North-East - West-South-West direction, and the fracturing gradient hardly reaches the value of 0.7 psi/ft. As a result of the above reasons the formations burst very easily, the resulting fractures are vertical and develop up to the surface, thus starting the formation of craters during well control operations.

FEATURES OF BLOWOUTS IN HUNGARY

Purposeful CO exploration based on geological and geophysical foundations was started in the Carpathian basin in the first decade of the century. Rotary drilling came into use from 1935 on, and here the existence of equipment for the prevention of blowouts was required by the provisions of the mining authorities.

One of the most specific causes of oil, gas and water blowouts in Hungary lies in the specific stratigraphic structure of the Carpathian basin and in the extraordinarily high formation temperature and pressure conditions due to the heat flux well above average.
The pressure conditions (1) shown in Figure 1 demonstrate that a great amount of prospecting work has found formations with pressure gradients of 0.9-0.95 psi/ft well above the pressure gradients of 0.47-0.48 psi/ft, which are considered to be representing hydrostatic pressure. Formations with abnormal pressure become increasingly frequent in the range of depth below 6200 ft. The regular use of mud with a density of 20 ppg was not a rare phenomenon.

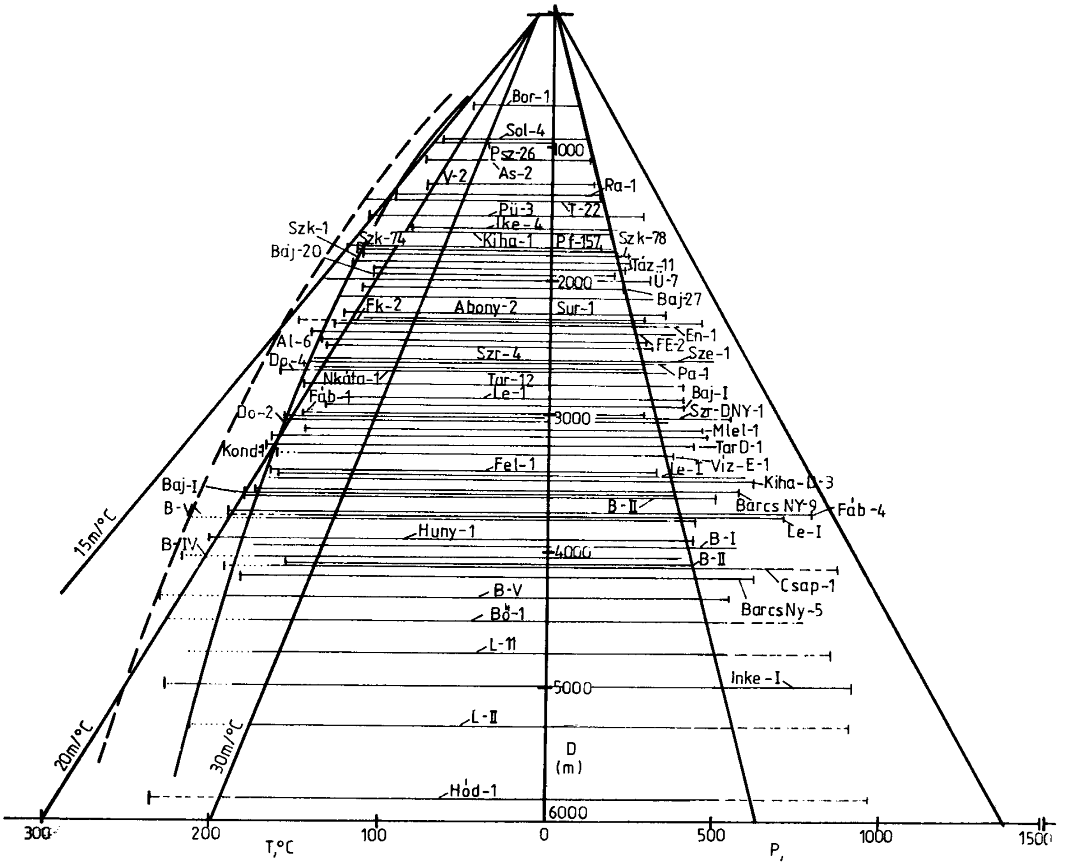


Figure 1 Measured temperatures and pressures in Hungary

The predictability of formations with abnormal pressure was made difficult not only by the fact that the equipment in the 1970s (MUDLOGGING) as well as the geophysical instrument park preparing the drilling were not ready for predicting abnormal pressure, but in many cases the geological conditions of the traps by themselves made prediction impossible (traps in fissured rocks of volcanic origin, thin overlaying marl, etc.).
Mud with high density (e.g. 20 ppg) that can be conditioned only by incurring high costs had to be made suitable for tolerating abnormally high temperatures. Exploration wells prospected formations with abnormal pressure and temperatures of 390 F° (200°C) in depths of 11500 ft (3500 m). In the drilling site named Hód-1 a temperature value of 465 F° was measured in a depth of 11000 ft, which was a temperature record. That temperature exceeds the final temperature of the drilling site KTB-1, which is registered as a European depth record. According to information available, it also exceeds the bottom-hole pressure of the world record holder-drilling site in the Kola Peninsula. It is a strange observation that a temperature gradient of 27.5 ft/F° was

measured in a depth of 4600 ft (1400 m), while a temperature gradient of 37 ft/F° can be considered as typical as of a depth of 13000 ft (4000 m).

Therefore the imbalances with the high mud costs typical of such areas are justified, which have resulted in blowouts on several occasions. At the same time, boring through formations with mud loss, i.e. with a pressure lower than that of the hydrostatic formations, makes drilling tasks even more complicated. In the now 9 decades of activities of the Hungarian hydrocarbon mining there have been 73 blowouts.

BLOWOUTS CASE STUDIES

The first blowout in the field occured in 1961, when the gas reservoir formations were opened to a depth of 4420 ft under the protection of a surface casing of 9 5/8 in of 1050 ft in length. It can be verified that it was because of swab pressure that the wellbore overflowed during completion. Although the wellbore was shut down with a blowout preventer according to regulations, the annular space continued to produce and became empty as a result of a plugging in the choke line hydraulic valve. In order to shut down the fully closing blowout preventer, the tool was dropped, the blowout preventer was shut down and well control was begun with mud of a density of 10 ppg. As a result of the pressures arising in the course of restoring the balance, fractures developed from the surface casing shoe to the surface which could be followed for 1980 ft closely symmetrically to the wellbore. A difference of 16 ft in height developed between the two sides of the crack. The gas flow started burning, rescue could not be continued, and three craters developed along the crack. In one of the cracks the drilling rig and the mast sank. The blowout came to an end as a result of a collapse of the formation, and today there is still a pond where the largest crater used to be. With the purpose of checking the gasification of the upper waterbearing strata, three exploration wells of 250 ft were drilled, which demonstrated the presence of gas in a depth range of 100 - 250 ft.

The next blowout took place in 1963, when the drilling was intended to be deepened under the protection of a casing of 9 5/8" of 1050 ft. Gas leakage occured next to the casing and it could not be stopped, therefore the decision to continue drilling was taken so that the leakage could be stopped by means of the next casing string. In the continued drilling, as a result of the swab pressure of the trip started in a depth of 1770 ft, the well overflowed, after shut-down of the blowout preventer the formation burst, the fractures led to the formation of craters and in a short time a crater with a diameter of 50 ft swallowed the drilling rig.

The third blowout in the field occured in 1987 and lasted for a very short time. The purpose of the drilling was to complete a gas production - gas injection well with a planned depth of 3200 ft. The casing string of 13 3/8" was not equipped with blowout preventers.

Drilling was performed after running in the conductor casing of 13 3/8 in of 78 ft cemented to the surface by means of a drilling bit of 12 1/4 in to a depth of 1670 ft in order to run-in a casing string of 9 5/8 in. The casing string was run in with a float shoe. When the casing string was run in a depth of 705 ft, the well overflowed. In the annular space the gaseous liquid rose very rapidly, then developed into a wild blowout in lack of a blowout preventer. A mere ten minutes after detection of the leakage around the rig, the soil burst in a semi-circle around the cement base. A 10 m deep crater with a diameter of 20 m producing a sandy mud with inflammable gases developed, which swallowed the rig three hours later. The blowout stopped due to a collapse of strata after a short time. On the day after the blowout only a slight gas leakage could be detected on the surface of water in a depth of 10-15 m in the crater.

BLOWOUT CAUSES

In order to ensure undisturbed drilling of production wells for the purpose of production from the Pannonian deposits, production was begun from the deposits close to the surface. In 1990 gas relief drillings were performed in the field in order to exploit the gas stored close to the surface (460-1066 ft) so that undisturbed drilling of production-injection wells could be ensured in the lower strata. During exploitation watery-sandy gas production of small yields and short duration was only achieved. It was proved that the deposits in the upper strata were not suitable for gas production. However, their presence represented a significant hazard of blowout in the course of drilling through the upper stratum.

Geophysical logging in the well was used for determining the location of shallow gas close to the surface as can be seen in Table 1.

Depth of shallow gas **Table 1.**

Depth (ft)	Absolute Permeability (mD)	Water saturation (%)	Contents
83-90	-----	-----	Solute gas
276-294	-----	-----	Solute gas
307-310	-----	-----	Solute gas
336-340	-----	-----	Solute gas
464-674	528 - 803	57 - 82	Primary VI.
585-590	748	78	Secondary V.
648-657	859 - 944	65 - 100	Secondary IV
830-832	123	74	Primary III.
983-997	676 - 604	73 - 61	Secondary II.
1046-1071	744	86	Primary I.

GAS DEPOSITS OF THE UPPER FORMATIONS

The geological processing of the layers differentiated between three primary (I, III and VI) and three secondary (II, IV and V) gas deposits. The secondary gas deposits developed probably from the lowest gas deposit (I) as a result of previous blowouts through underground flow.

The reservoir rock is a loose sandstone or sand with hardly any bonding matter and of varying clayey development.

The blowouts outlined in the case studies occurred in shallow gas formations, with the depths of the deposits between 100 ft - 2000 ft verified and demonstrated by measurements. The origin of the deposits is disputed as to what extent they are the results of geological development or of underground flow caused by the first blowouts. An analysis of the first blowout makes it probable that shallow gas was deposited in geological periods, although it is possible that further underground flow resulting from the blowouts worsened the situation. The intensity, erosive effect and rapidity of the blowouts also justify the qualification as shallow gas.

Well overflows were caused in every instance by the swab pressure resulting from the tool movements, whose intensity was considerably increased by the bad rheological properties of the mud.

WELL STRUCTURE

According to the experience of the blowout in 1961, the surface casing shoe had to be set at least in a depth of 1650 ft for opening the productive formation. Drilling through the shallow gas between 115 and 1071 ft in section 12 1/4" and isolating it by means of the casing string continued to involve a significant hazard of blowout. The strength of the loose formations around the shoe of the 13 3/8" conductor casing in a depth of 115 ft amounts only to 70-80 psi, therefore a blowout preventer was mounted on the well head only after running in a 9 5/8" casing.

All traditional well control methods were foiled by the use of the traditional well structure:

- a casing in a small depth,
- small fracturing gradient and
- the fact that fracturing led to vertical fractures up to the surface which resulted in the development of a crater in a short time.

Hungarian research [2] shows that the Poisson ratio can be taken to have a value of 0.4, which gives from the *Ben Eaton* relationship the following formula:

grad P frac = 2/3 grad P overburden + 1/3 grad p formation

which gives the fracturing gradient of the field as very low, 0.68 - 0.73 psi/ft (0.154 - 0.165 bar/m).

The considerable gas yield developed from the under-compacted formations with significant permeability led to the rapid erosion of the well control equipment as a result of the high sand contents.

DEVELOPMENT OF WELL CONTROL SYSTEM

As a result of the blowout in 1987, in the course of further drilling in the field the drilling technology was modified so as to moderate the causes of kick.

MODIFICATION OF THE WELL STRUCTURE

The well structure of the wells drilled after 1987 underwent significant changes. The initial drilling section had to be drilled with a 24" section instead of an initial diameter of 17 1/2". The shoe of the 18 5/8" casing had to be at a depth of minimum 180 ft instead of the previous shoe location at 110 ft of the 13 3/8" casing. Drilling is to be continued with a section of 17 1/2" to 500 m instead of the previous 12 1/4" section, for the same reasons as in the initial drilling. That section is to be secured with a 9 5/8" casing. The data of the well structure prior to 1987 and of the modified structure are summed up in Table 2.

Well structures of the Hajdúszoboszló field **Table 2**

	Before 1987		After 1987		Recommended well structure	
Well structure	**Size**	**Length (ft)**	**Size**	**Length (ft)**	**Size**	**Length (ft)**
Open hole	**17 1/2”**	110	**24”**	185	**24”**	110
Casing	**13 3/8”**	**105**	**18 5/8”**	**180**	**18 5/8”**	**105**
Open hole	**12 1/4”**	1660	**17 1/2”**	1660	**17 1/2”**	445
Casing	9 5/8”	1650	9 5/8”	1650	**13 3/8”**	440
Open hole	8 1/2”	3000	8 1/2"	3000	**12 1/4”**	1660
Casing	7"	3000	7”	3000	9 5/8”	1650
					8 1/2"	3000
					7”	3000

ADVANTAGES OF THE MODIFIED WELL STRUCTURE

- The conductor casing shoe is located somewhat deeper, and thus slightly increases the fracturing pressure.
- In the dismantling and completion, as well as the casing operations, the swab and surge pressures decrease in an annular space of a larger cross sectional area. The advantage of using larger well bores and casing diameters lies in the fact that running a 9 5/8" casing in an open 17 1/2" hole induces considerably smaller swab and surge pressures than running the same casing in a 12 1/4" section.

FURTHER STEPS:

- Mud weight has been decreased, and overbalance does not exceed 100 psi.
- In order to decrease swab and surge pressures:
  - more stringent check of the rheological properties of mud is required,
  - the bottomhole assembly sizes are revised,
  - the cross sectional area of drill nozzles has been increased,
  - a strict hole fill system has been introduced (trip tank, trip sheet).
- Strict regulations have been introduced for casing and cementing operations.
  - In order to prevent a dangerously swab and surge pressure, the running-in rate of casing has been decreased. Furthermore, it is forbidden to run in 9 5/8" casing with float shoe, differential casing shoe is to be used.
  - Enhanced attention is to be given to kick signs as well as to changes in the mud parameters.
  - The drilling engineer is to be present on site when running in the 9 5/8" casing string.
  - A special seal has been developed for sealing the 18 5/8" - 9 5/8" casing annulus.
  - In order to prevent the build up of high pressures on the formation, cementing the 9 5/8" casing has to be performed in two stages, where the location of the stage collar is determined by logging. The casing string is to be cemented up to the surface.

MODIFICATION OF THE CHOKE MANIFOLD

- The 18 5/8" casing is to be provided with a blowout preventer, which was not used before 1987. At present a 20 3/4" ram type blowout preventer is used.
- Between the blowout preventer and the casing head there is an 18 5/8" drilling spool. The drilling spool is provided with a 6" and a 3" outflow connection. Its role is to divert the gas reaching the surface immediately if the blowout preventer should be shut down and thus to prevent the soil from bursting and craters from developing.
- The 3" choke line in connected to the choke manifold. The choke should be open to facilitate free relief of the gas. The 6" vent line should be open towards the pit when the 17 1/2" section is drilled. The 6" vent line is to be fitted with a 3 bar rupture disc.
- In case of kick it is forbidden to shut down the choke manifold. If there is a kick, a circulation should be brought about, thus it is possible to prevent the well from filling with pure gas, which would give rise to the most dangerous situation.
- The state of the choke manifold is to be checked at the beginning of every shift.
- Critical drilling operations must be performed only by day.

RECOMMENDED MODIFICATIONS

The measures taken after 1987 have greatly reduced the possibility of the development of a kick. It is, however, not clear that if, for any reason, there is a kick, whether it is possible to control the well or a wild gas blowout leading to crater formation is to be expected. Therefore a simulator analysis was performed on the basis of the well construction used after 1987 together with the well data. A well control simulator CS DPWS-22 was used for the analysis in 1997 using the results of previous simulations [3]. The simulator analysis was performed with consideration of the measures introduced after 1987. The main steps of the simulation are as follows:

Assumptions:

A kick occurs during drilling at a bottom at 1070 ft. Formation fluid only enters from the reservoir at 1046 - 1071 ft. (Reality is more disadvantageous, for a kick is expected to lead to a rush in from reservoirs above 1046 ft.). The formation pressure is hydrostatic.

The fracturing gradient is 0.7 psi/ft (0.16 bar/m)

Well construction:

- 18 5/8" conductor casing (shoe depth: 160 ft)
- 17 1/2" open bore with a depth of 990 ft
- 5" drill pipes and 6 1/2" drill collars
- The 18 5/8” casing is equipped with blowout preventer.

Procedures:

1. Starting a mud pump when overflow is detected.
2. Shut-in of the blowout preventer, assuring free outflow of the formation fluid through the open 6" vent lines and the 3" choke lines.
3. Because of the closeness of the casing shoe to the surface, well control is controlled by keeping the casing pressure at a constant value, which also ensures a steady pressure at the shoe with an accuracy of appr. 10 psi.

In the simulator analysis of the method well control was still unsuccessful after 10 hours. Considering the fact that in the field the free outflow of the formation fluid resulted in the formation of a crater in a few hours, well control cannot be accomplished with this method.

Selection of well control method

In selecting the well control method the following three specific problems had to be considered:

- Well construction: The casing shoe at a small depth, as a result of which the MAASP value is very low (115 psi),
- The situation of the gas reservoirs: In the well bore are open several shallow gas reservoirs with hydrostatic pressure. In a kick simultaneous gas inflow from several formations is to be expected depending on the location of the bottom of the hole.
- Blowout characteristics: In previous experience the flow took a short time to appear at the surface after a kick had begun. The outflowing gas carried both sand and water. In a few hours after the beginning of a blowout, crater formation began without the well being shut down.

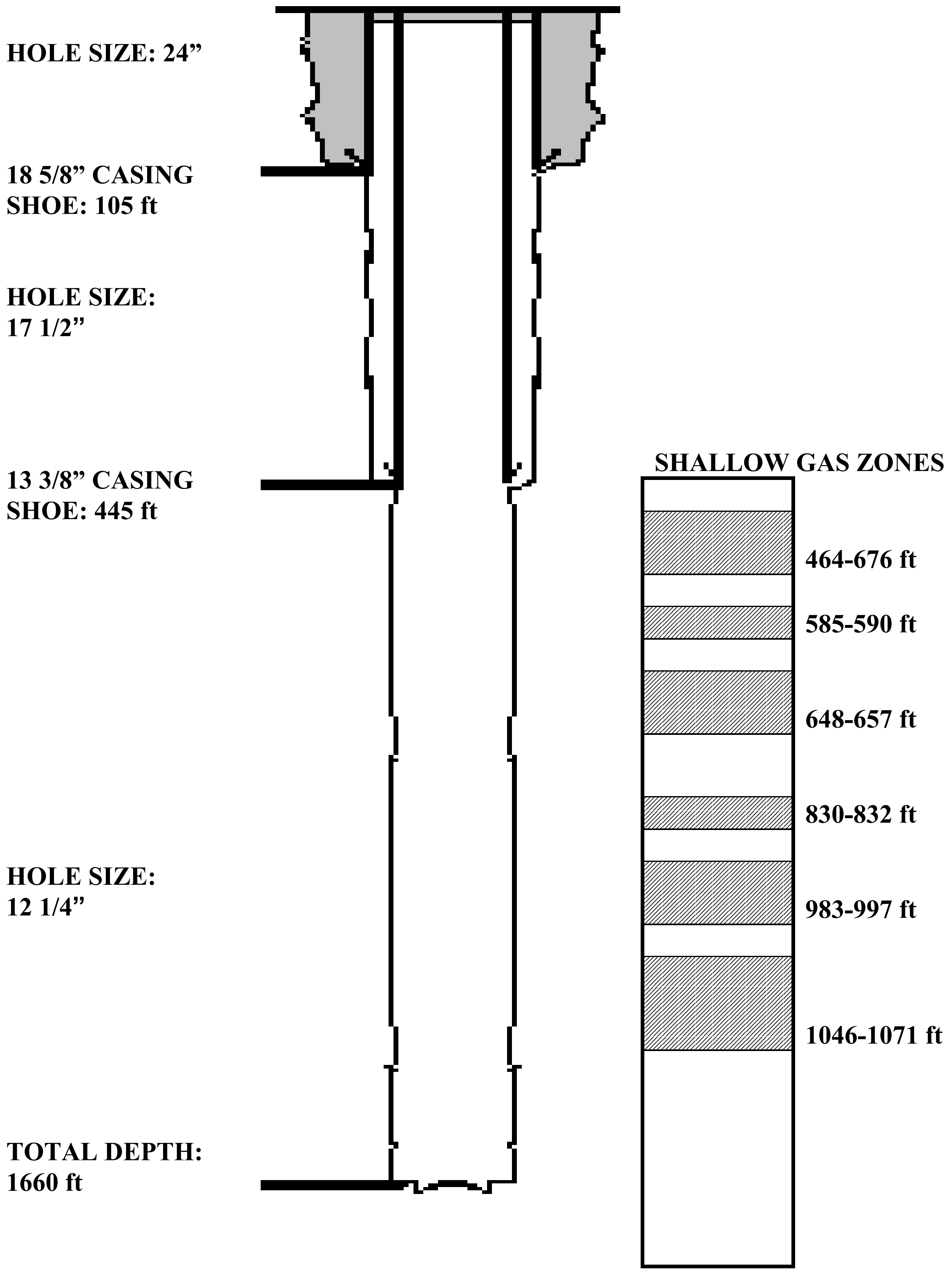
On the basis of the simulation the following measures produced a result:

1. A modification of the well construction is essential (see Figure 2.):
    - The depth of the 18 5/8" casing string shoe can be reduced to 100 ft.
    - The 13 3/8" casing string is to be run in above the first gas deposit to a depth of 440 ft, thus increasing the fracturing pressure at the shoe to 310 psi.
    - The 13 3/8" casing string is to be provided with a blowout preventer.
    - It remains necessary to complete the choke manifold with a 6" vent line a 3" choke line.
    - Shallow gas reservoirs between 464 and 1071 ft are to be drilled with a 12 1/4 well bore.
2. The choke manifold and the vent line are to be kept open during drilling.
3. If an overflow is detected, the pump is to be started immediately. When is kick is detected, the blowout preventer is to be shut down and the flow of the well stream is to be ensured through the open vent line.

The well control operation can be controlled by means of drill pipe pressure and the limitation of MAASP. A small back pressure, which is allowed by a fracturing pressure of 310 psi at the shoe, can also be applied. The simulator makes it possible to monitor the pressure developing at the casing shoe during well control as well as the annular surface pressure.

By using the above method, well control was accomplished in a relatively short time after the gas inflow.

Figure 2.: Recommended well structure



TRAINING

The well control method developed differs from the "hard shut-in" method widely applied. Because of the conventional well shut-in methods which the drilling crews are used to, an incorrect application of the method developed specifically for the field may result in blowouts accompanied by crater formation and loss of the rig. The simulator analysis of the well control situation also offers the possibility of training the drilling crew. Therefore it is necessary to organize simulator training with consideration of the local specialties before beginning the drilling operations planned in the field in order to prevent major problems [4].

CONCLUSIONS

Drilling through shallow gas formations in the Hajdúszoboszló field resulted in several blowouts accompanied by crater formation and loss of rig. After 1987, measures were taken to prevent kicks in order to enhance drilling safety. In order to prevent major swab and surge pressure, the well bore diameter was increased, run-in speed was limited and an appropriate mud program was selected. The conductor casing was equipped with vent line and blowout preventer.

The simulator analysis of the blowout prevention system implemented after 1987 showed that safe well control required further modifications. It becomes necessary above the known shallow gas reservoirs to run in a casing string which is to be equipped with a blowout preventer. The well construction modified in this way and the well control method developed by the simulator analysis facilitate a controlled well control operation.

Early recognition of a kick as well as safe application of the well control method differing from the traditional ones necessitate the organization of simulator training with consideration of the local characteristics. Shallow gas deposits will continue to pose problems. However, it has become possible to prevent blowouts by appropriate training of the personnel and applying state-of-the-art technology.

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