



Excel Sheet Program to Select Optimum Well Kill Method during Drilling

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Abstract

Well control is an extremely critical operation that requires a lot of good planning and professional implementation. The selection of the proper kill method that is required to kill the well safely and efficiently either drilling or production well is a tedious decision. It requires a lot of accurate data from the current well conditions which will help the decision makers in their selections. Selecting the wrong kill method may end up with an unsafe and a high costly operation. This paper introduces an excel sheet program to select optimum well kill method that will help the engineering team as well as the operation team to take the proper decision regarding the optimum well control method to be applied.

This paper provide a program built using simple excel sheet in which input data are well information. This information is analyzed and used to answer some questions. The answers for these questions have different weights. The system will select the highest score for these answers which will choose the optimum kill method based on the input data and the weighted value and provide kill sheet for the well according to the selected method.

The program is tested in two different cases for drilling oil and gas wells. The system selected different kill methods based on each well criteria. The outputs were compared with a commercial simulator and the results are comparable which indicate that such a cheap excel program can be used easily and economically.

Introduction

The main objective of any drilling program is to help assure a well to be drilled, completed, and produced safely economically and efficiently. Due to the complications that are added to the drilling and production processes, a lot of challenges are caused to the operation. A lot of blowouts have been caused because of not following the proper kill method or the proper procedures. These blowouts caused a lot of fatalities, loss of rigs, loss of equipment,

damage to environment and loss of production. Recent blowouts and well known in the industry are the blowout happened in the Gulf of Mexico in 2010 (Macondo well) and the blowout happened in Temsah field in 2004.¹

Well Control in drilling wells may be controlled by different kill methods. Each method has different applications. The Driller's method is preferred if the kick size is lower than the kick tolerance volume, deviated and horizontal wells, the string is on bottom, and

Quick Response Code:



***Corresponding author:** Abdel Alim H El Sayed, Cairo University, Egypt

Received: 25 February, 2023

Published: 14 March, 2023

Citation: H El Sayed AA, Elkamash HM, Guo C. Excel Sheet Program to Select Optimum Well Kill Method during Drilling. *Trends Petro Eng.* 2023;3(1):1-16. DOI: [10.53902/TPE.2023.03.000521](https://doi.org/10.53902/TPE.2023.03.000521)

in case of gas migration where the kill mud is not ready. The wait and weight method is preferred if the kick size is within the kick tolerance calculations, no gas migration is encountered, vertical wells where the volume of the string is lower than the volume of the open hole section. The volumetric method is preferred than the other methods in case the drill string is off bottom, drill string washout, gas migration, hole pack off, totally plugged string or no string is in the well bore. After the volumetric method, lubricate and bleed method has to be used to get rid of the gas. The stripping operation is preferred if the string is off bottom, and the gas is not migrating, and the gas volume is within the kick tolerance calculations. And in case of gas migration, the combined volumetric and stripping operation can be used.

The selection of the proper kill method is challenging and will depend on a lot of factors. These factors are necessary to help and guide the operation team to select the required kill method. However, it will be a critical decision as it will require the knowledge of the different conditions currently in the well. Commercial software are introduced to the industry, but they offer the calculation of the kill sheet and steps to be followed and amount to be monitored during applying the selected technique. Therefore, the need for computerized program to select the optimum method quickly and efficiently is obviously interested for the industry that will help the operation team to select the proper kill method to bring well back under primary control condition as well as the kill sheet calculations.

Background

The flow of the formation fluid from the formation into the wellbore is called "kick". It is also called "influx" if the well still overbalance. If the kick is not controlled, it may led to a blowout. Well control procedures are intended to safely prevent or handle kicks and reestablish primary well control conditions by regaining the hydrostatic overbalance of the mud. During the drilling operation, well control barriers should be in place to control the well. The primary well control barrier during conventional drilling is the hydrostatic pressure of the mud that provides overbalance on the formation being drilled which prevents formation fluid flowing into the well. For example, as shown in Figure 1, if the hydrostatic pressure is 5,200psi at 10,000ft (10.0ppg mud) and the pore pressure is 4,650psi. The difference between the hydrostatic and pore pressure is 550psi; so, the well will be static, and this state is identified as overbalance condition. To control the well, the well should be overbalanced, and this to be planed based on each company policy.²

An overbalance should be maintained during the drilling and tripping operation. The value of the overbalance depends on company policy (normally in a range between 100 to 300psi). If the hydrostatic pressure fails to maintain the overbalance and fails to prevent formation fluids from entering the wellbore, the well will

flow and kick is occurred. This process is stopped using the secondary barrier which is the blow out preventers (BOP) to prevent the escape of the wellbore fluids from the well. This is the first stage of the secondary well control. BOP should be tested regularly as per API and/or company policy to make sure that its reliability in case of any well kick and control operations. If the formation cannot be controlled by the primary or secondary well control, tertiary well control will be considered as the third line of defense. Drilling a relief well is considered one of the tertiary well control processes.²⁻¹¹

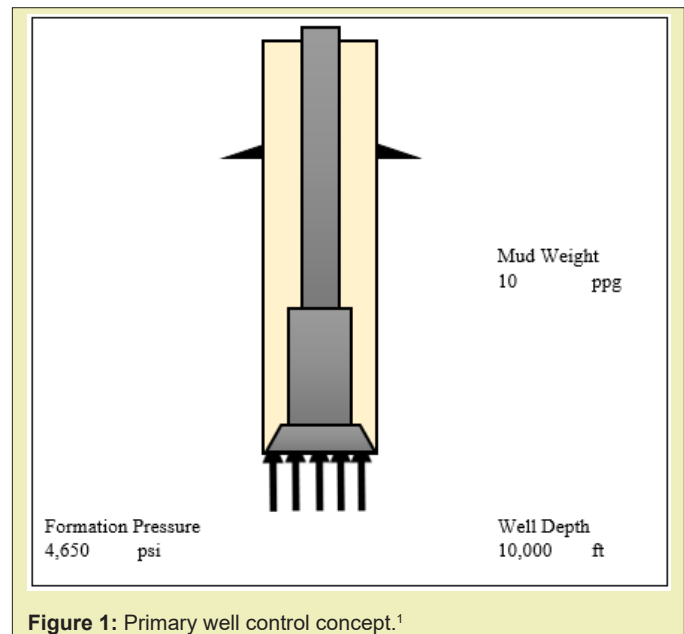


Figure 1: Primary well control concept.¹

In order to implement plan, drill and complete the well safely, it is necessary to have some knowledge of the fracture pressures of the formations to be encountered. The maximum kick size to the wellbore depends on some factors, these factors are the kick intensity "KI" and the fracture pressure of the weakest formation in the wellbore.²

If the wellbore pressure (hydrostatic pressure) is equal to or exceed this fracture pressure, the formation would break down as induced fracture would be initiated, followed by loss of mud, loss of hydrostatic pressure and loss of the primary control. Fracture pressure is a function of the weight of the formation matrix and the fluids occupying the pore space within the matrix, overburden pressure of the formations above the zone of interest. These three factors are combined to produce what is known as the fracture pressure.¹⁻¹⁰

In onshore locations, since the sediments tend to be more compacted, the overburden gradient can be taken as being close to 1.0psi/ft. While in offshore, the overburden gradients at shallow depths will be much less than 1.0psi/ft due to the effect of the seawater depth and the large thicknesses of unconsolidated sediment. This makes surface casing seals in offshore wells much vulnerable

to breakdown and is the reason why shallow gas kicks is difficult to be shut in.²

Maximum Allowable Annular Surface Pressure (MAASP)

The formation strength normally determined from the leak-off test below the casing shoe using the following Equation 1. MAASP is the maximum allowable annular surface pressure that can be tolerated before the formation at the shoe tend to fracture. MAASP can be determined using one of the following Equations (Equations 2, 3 or 4). It is only valid if the casing is full of the original mud, if the mud weight inside the casing is changed, MAASP must be recalculated. The calculated MAASP is no longer valid if the influx fluids enter into the casing.³

$$P_{F@shoe} = P_s + P_{h@shoe} \quad 1$$

$$MAASP = P_{F@shoe} - P_{h@shoe} \quad 2$$

$$MAASP = (FG - MG) \times TVD_{Shoe} \quad 3$$

$$MAASP = (MAMW - MW_{current}) \times 0.052 \times TVD_{Shoe} \quad 4$$

Kick Tolerance

Kick tolerance can be defined as the maximum kick size at a certain kick intensity that the well can be safely shut in and circulated out of the well without fracturing the formation at the weakest point in the open hole. In critical sections, it is important to calculate kick tolerance on a regular basis. A lot of factors can affect the kick tolerance size. These factors are the mud density, the bottom hole assembly, the hole depth, the pore pressure, the type of the kick, etc.⁵

The drilling engineer must calculate the volume of gas influx that can be safely shut in and circulated to the previous casing shoe for each open hole section. These calculations should consider the maximum expected pore pressure, and this will be used to calculate the maximum kick size. The worst-case scenario for a kick occurring is at the greatest depth – when the next casing point has been changed (section TD). To determine the minimum shoe strength required to reach this, some assumptions are made. For a development well, assume that the kicking formation may have a pore pressure equal to the virgin pressure of the first well drilled in that field. During this study the formation pressure is driven from the SIDPP and the hydrostatic pressure inside the drill string. Once the fracture gradient is known, calculate the maximum gas influx volume at the next casing point (section TD).⁴

To calculate the kick tolerance, Engineering or operation engineers have to calculate the maximum kick length which may be encountered at initial shut in or when the top of the gas is at the shoe. This length can be calculated using Equation 6. Then they have to convert the length calculated in the previous step into volume. This volume will be calculated two times, one time around the BHA

and the second around the drill pipe below the casing shoe. Using Boyles law in Equation 7, will help to convert the calculated volume at shoe into the downhole condition assuming constant temperature and ideal gas.⁴

$$L_{max} = \frac{MAASP - SIDPP}{MG - IG} \quad 6$$

$$P_1 \times V_1 = P_2 \times V_2 \quad 7$$

$$V_1 = L_{max} \times C_{DP\&OH} \quad 8$$

At initial shut-in,

$$V_1 = L_{max} \times C_{BHA\&OH} \quad 9$$

Note: Kick Tolerance will be the smaller of the two volumes (V_2 calculated from Equation 7 and V_1 calculated from Equation 9).

As shown in Figure 2, two scenarios that will give the maximum shoe pressure. The maximum shoe pressure will be either at initial shut-in Figure 2a as the gas will be around the drill collars taking high length, or when the gas is at the shoe of the last casing string Figure 2b where it will take a different length due to the gas expansion. As mentioned in the previous paragraph, it is recommended to calculate the two lengths and then calculate the gas volume in each case, then compare the initial volumes in each case and the lowest volume will be the kick tolerance volume.⁹

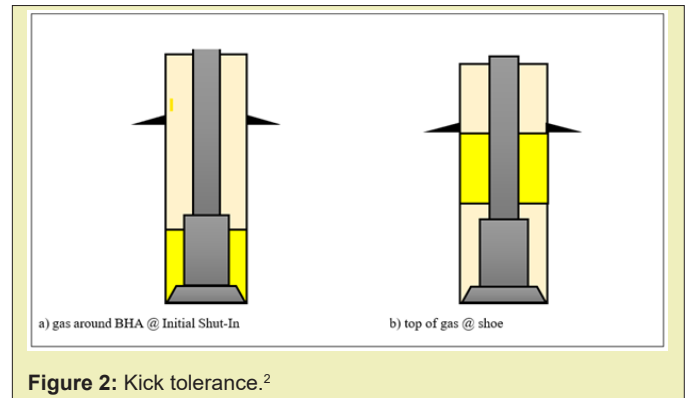


Figure 2: Kick tolerance.²

Kick tolerance will always be calculated at the well design stage as it is one of the drivers towards the selection of casing seat and casing specifications. The company policy should be followed before the acceptance of the drilling program and before the drilling operation.³

Causes of Kick

There are a lot of causes that may end up with a well control situation due to the loss of the overbalance situation. These causes can include, and are not limited to, improper hole filling during tripping out of the hole, swabbing during the pipe movement, loss of circulation, the usage of insufficient mud weight, drilling through abnormal formation pressure, and some other special operations like Drill Stem testing, drilling into an adjacent well and/or excessive drilling rate through a gas sand. Surveys in the past have shown that

the major portion of well control problems have occurred during tripping. This is due to reduction in the BHP due to; diminishing of annular pressure loss with pumps off, drop in the annulus levels when pulling the drill string out of hole and not filling the hole with the proper displacement and/or, due to swabbing effect.²⁻⁹

The pressure differential between the formations and wellbore, degree of underbalance, is proportional to the influx flow rate and kick volume for a given flow period. The situation can only deteriorate with time because the less-dense formation-fluid volume enters the hole and reduces the buttonhole pressure and thereby serves to increase flow rate into the well. Permeability is another significant factor as well as exposed thickness and fluid viscosity. It is difficult to control permeability or reservoir fluid properties, but the amount of exposed rock is governed by how long the driller continue to drill with kick entry. Gas influx in the well can be expected using the following equation and depends on the exposure time.⁴

$$q_{gsc} = \frac{703 K_g h (P_e^2 - P_wf^2)}{\mu_g T_z (\ln(r_e/r_w) - 0.75)} \quad 5$$

Insufficient mud weight is the main cause of underbalance and eventually kicks while drilling. The ECD is considered one of the causes that may end up with well control situation. If the ECD exceeded the formation fracture pressure, downhole losses will occur and cause the fluid level to drop resulting in the reduction of the hydrostatic pressure above the formation and initiating underbalance. If the well becomes underbalanced, it will start to flow and kick generates. The ECD may increase due to increase in the mud weight, increase in the mud rheology, small annular clearance between the bottom hole assembly size and the open hole diameter, increase in the pumping rate, increase in depth or due to increase in ROP and loading the annulus with cuttings. Proper planning should be in place to make sure to drill different formations within the same mud window and to control the mud weight and ECD as planned. Failure to prevent such kicks often leads to underground blowouts.⁸

Kick Indicators

During the normal drilling or tripping operation, operating parameters should be recorded and analyzed for any anomalies. Kick warning signs are considered some of these anomalies. Observing the warning signs will help to secure the well in case of kicks or even it will reduce the kick size as low as possible. The warning signs can vary from one situation to another. The warning signs are summarized as following: increase in rate of penetration, increase in torque and drag trends, decrease in shale density that can be captured from the downhole logs, changes in mud property, changes in cuttings size and shape, increase in the trip gases, increase in the connection and/or background gas during drilling, increase in the temperature of the return drilling mud and/or, decrease in D-ex-

ponent. The observation of positive indicators is a clear message that the well is underbalance and a kick is in progress. Positive indicators are increase in the return flow percentage, increase in the active tank volume and/or flow while pumps are off. The right decision to the observation of any of the positive indicators is to check for flow. If well flow while the pump is off, shut in the well using the proper shut-in procedures as per the company policy. After that choose the kill method and start performing killing procedures.¹⁰⁻¹⁹

Kick Behavior

Well kick may consist of water, oil, gas or any combination of them. The mud weight is usually heavier than the kick. The killing operation should proceed to remove the kick from the wellbore or pushed back to the formation. [9]

Gas Influx

Kick types have different compressibility. One of the conditions affecting the wellbore pressure is the kick compressibility. Gas is one type of the expected kick fluids. The gas compressibility is high compared with the other kick fluids, the temperature and pressure affect the gas volume while being circulated out of the wellbore. For example, a well is shut in on 1bbl gas kick at 10,000ft. The current mud weight is 9.0ppg. The BHT is 170 °F. The hydrostatic pressure of the current mud is 4,680psi. If the gas is allowed to expand, its size will increase to 280 barrels at surface under atmospheric conditions (assuming 0.6 specific gravity gas at 80°F and 14.7psi). If that barrel of gas is not allowed to expand in a controlled manner as it is circulated up the well bore, it will nearly maintain its initial pore pressure as it moves up the annulus and may create excessive well bore pressures. This excessive pressure may cause formation fracture resulting in downhole losses, and underground blowout.²⁰⁻³⁰

In OBM, Gas has high solubility and the kick detection is challenging which requires good training and special awareness of rig crew. The gas will come out of solution when it approaches the bubble point pressure. The gas expansion will be very fast when gas is near to the surface. The main factors affecting the solubility are fluid type, temperature and pressure.²

Well Control Procedures

Many well control procedures have been developed over the past years. The aim of these methods are to bring the well to its original normal case to continue drilling safely, Figure 3. The constant bottom-hole pressure concept was developed in which the total pressures (mud hydrostatic pressure, casing pressure, etc.) at the bottom of the hole would be maintained at a value slightly greater than the formation pressure to prevent further influxes of formation fluids into the wellbore. This concept can be implemented in two ways.⁹

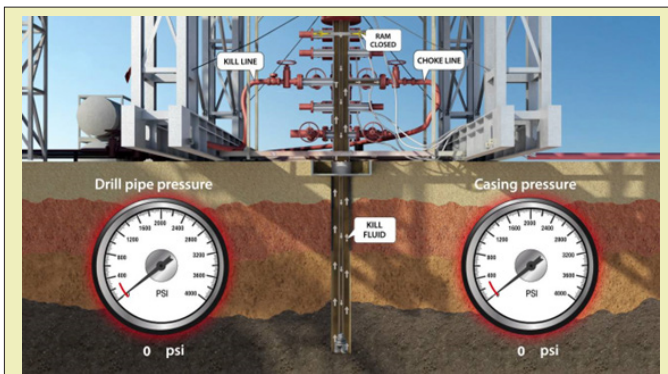


Figure 3: Results of kill method.³¹

The kill method can be done through one circulation or what is called the Wait and Weight method. After the well has been shut in, the kill mud will be prepared based on the recorded data. A drill pipe pressure schedule should be prepared. The formation fluid and the original mud will be displaced with the kill mud in one circulation. (An alternate name often applied is the engineer's method). Another method will include two circulations, or what is called the Driller's Method. The first circulation will be at least bottom's up and during this circulation the original mud will be used to displace the kick outside the well. The second circulation will be a total cycle which will include displacing the original mud with the kill mud. Both methods will apply a constant BHP which is slightly higher than the pore pressure and named kill circulation methods Figure 2.²

In some cases, Driller's Method and Wait & Weight method are not applicable. An alternative method should be used based on the well conditions. Unconventional, non-circulation, methods include the volumetric method, Lubricate and bleed method, stripping operation, combined volumetric and stripping operation, and Bull-heading.¹³

Building the Excel sheet

During the drilling operation, it is crucial to maintain enough overbalance to keep the formation fluid inside the formation. This can be accomplished by selecting the proper mud weight that will provide the required overbalance. There are a lot of causes that will end up with underbalance situation where the well have to be secured and proceed with the killing operation in order to regain the required overbalance. As mentioned in the previous chapters, there are different types of well control (killing) methods that can be used to regain the primary well control (overbalance).

The selection of the proper killing method is essential to control the well safely and to be able to continue drilling as planned. The selection process for the preferred kill method for drilling operations at different conditions will be justified. This study is based on building an expert system that depend on the advantages and dis-

advantages of each kill method. The system is built on Excel sheet program.

The Excel sheet program will be mainly based on input data provided by the user. These data will be justified in the form of questions answered by yes or no and based on the actual well data during the well control operation. The program is going to select the proper kill methods based on the input data. The required calculation for the selected kill method will be provided by the sheet program. The user can use this program to control the well and regain the overbalance. It is highly recommended to input all the required data which will help to get the best outputs from the system. The system is divided into inputs that is required from the user and outputs that will be used by the user to control the well.

For the program depends on 12 questions that will be answered based on the input data provided by the user. The weight for each question is generated based on more than 200 trials done on the program and confirmed the optimum weights. The questions need to be answered by Yes or No. These questions are:

1. Is the bit on bottom?
2. Is circulation valid through drill string?
3. Is the well vertical?
4. Is the well deviated?
5. Is the well horizontal?
6. Is the open hole volume less than drill string volume?
7. Is the kick gas (gas migration)?
8. Is the kick water?
9. Is the kick oil?
10. Is the Influx volume below kick tolerance?
11. Is the kick has a potential of H₂S?
12. Is the formation has good injectivity?

Program Input

The main input requirements are the existing well data as shown in Figure 4. These information input data includes:

1. Field Data
2. Formation Strength Data
3. Pump Data
4. Well Data
5. Shut-in Data

Program Processing

The program is going to calculate the well volumes, kick tolerance, kill method selector tool and different calculations for each

kill method. The kill methods covered for the drilling wells' well control are, Driller's method, Wait and Weight method, Volumetric

method, Lubricate and Bleed method, Stripping method, Combined Volumetric and Stripping method and Bullheading method.

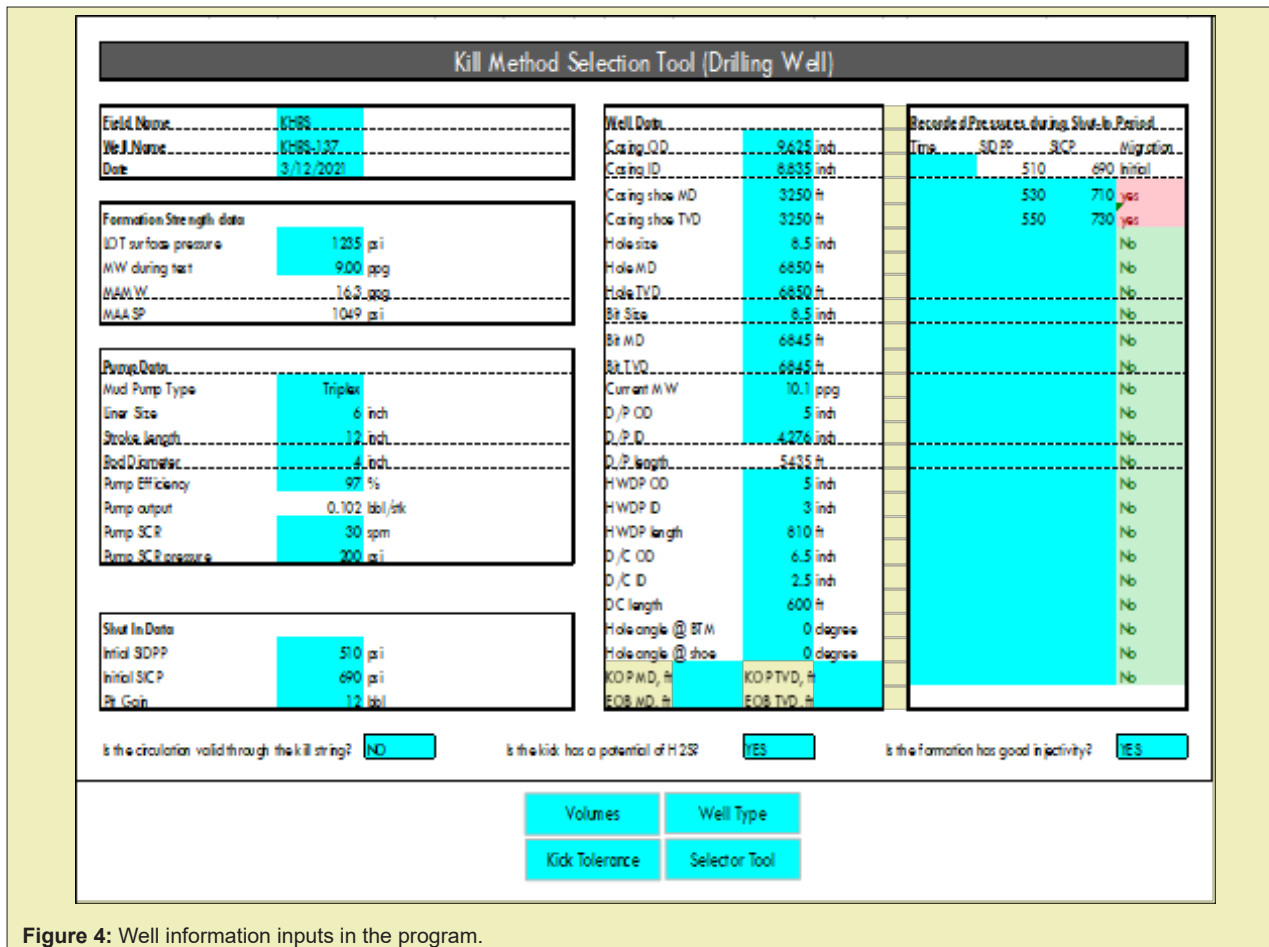


Figure 4: Well information inputs in the program.

Based on the current string (dimensions and length) and well information, the ESTOK system is going to calculate the different volumes inside the wellbore as shown in Figure 5. The kick tolerance section is going to calculate the maximum allowable kick size based on the current well design, SIDPP and current mud weight. It is going to calculate two values. The first value will be based on the initial shut-in when the kill is around the Bottom Hole Assembly (BHA). The second value will be based on the maximum gas expansion in the open hole and this will be when the top of gas reaches the shoe. The maximum kick size will be the lower of the previous two values. The kick tolerance calculations is shown in Figure 6.

The kill method selector tool section, Figure 7, is going to show the most likely kill method that can be used to kill the well according to the provided data in the input section. This section mainly depends on twelve questions which already captured from the input data. These questions are: is the drill string on bottom? Is circulation valid through the string? Is the well vertical, deviated or horizontal? Is the drill string volume bigger than the open hole vol-

ume? Is the kick type gas, oil or water? Is the kick volume below the kick tolerance volume? Is the kick has a potential of H₂S? Is the formation has good injectivity? Based on the weight of each question. Each question is answered automatically by yes or no. The program gives a value for each kill method depends on the user input data. The values are summed up for each kill method. The highest score of the answers will determine the optimum kill method.

In the Kill method selection tool section, the user will check the provided graph that shows the maximum selection index as shown in Figure 7. Based on the selected method, the user will click on the proper link for this selected method where the link will direct him to the final calculations for this method. For example, bullheading operation is selected kill method shown in Figure 3.

Program Output

The system will provide the user with the required calculations for the optimum kill method as shown in Figure 8 which is named kill sheet of the well.

Well Volumes		
Drill Pipe volume	96.54 bbl	948.05 stks
HWDP volume	7.08 bbl	69.55 stks
DC Volume	3.64 bbl	35.78 stks
Drill String Volume	107.26 bbl	1053.37 stks
Ann. Open Hole volume	155.31 bbl	1525.23 stks
Open hole	0.35 bbl	3.45 stks
D/C & OH	17.49 bbl	171.72 stks
HWDP & OH	37.18 bbl	365.12 stks
D/P & OH	100.29 bbl	984.93 stks
Ann. Cased Hole volume	167.51 bbl	1645.06 stks
Total Annulus volume	322.82 bbl	3170.29 stks
Total Well Volume	430.08 bbl	4223.66 stks

Input	Well Type
Kick Tolerance	Selector Tool

Figure 5: Well volumes calculations from the program.

Kick Tolerance calculations		
Expected Influx grad.	0.088 psi/ft	
Pform	4107.6 psi	
Hmax	1233.22 ft	
Vinflux	35.94 bbl	at initial shut-in
Vinflux	37.98 bbl	Top of gas @ shoe
Kick Tolerance volume	35.94 bbl	
Kick intensity	1.43 ppg	

Input	Well Type
Volumes	Selector Tool

Figure 6: Kick tolerance calculations from the program.

Results and Discussion

The program is applied on tow actual case to validate its results. The following are the results of these two cases studied by the program.

Case Study 1

The first well was a vertical well with a total depth of 6,850ft MD/TVD. The 9-5/8" casing was run and cemented at 3,250 ft MD/TVD. A leak-off test was conducted at 3,260ft MD/TVD. The leak-off pressure was 1,235psi with 9ppg mud. The 8-1/2" hole was drilled with 10.4ppg mud to 6,850ft. A kick was observed during the drilling operation at 6,850ft MD/TVD. The well has been shut-In and the surface pressures were recorded. No gas migration was detected. It was recorded from the offsets that there was no potential of H₂S gas during kill operation. The well conditions were inserted in the excel sheet program as shown in Figure 9.

From the program output kick tolerance calculations, the current kick size is within the kick tolerance volume as per Figure 10. The maximum allowable kick size before the casing shoe breakdown was 41 barrels and the kick size was 14 barrels. From the program selector tool, the system recommended to use the wait and weight method as shown in Figure 11 and this was shown in the graph that shows the highest Selection Index. Thus, the Wait and Weight method is the optimum kill method for this case.

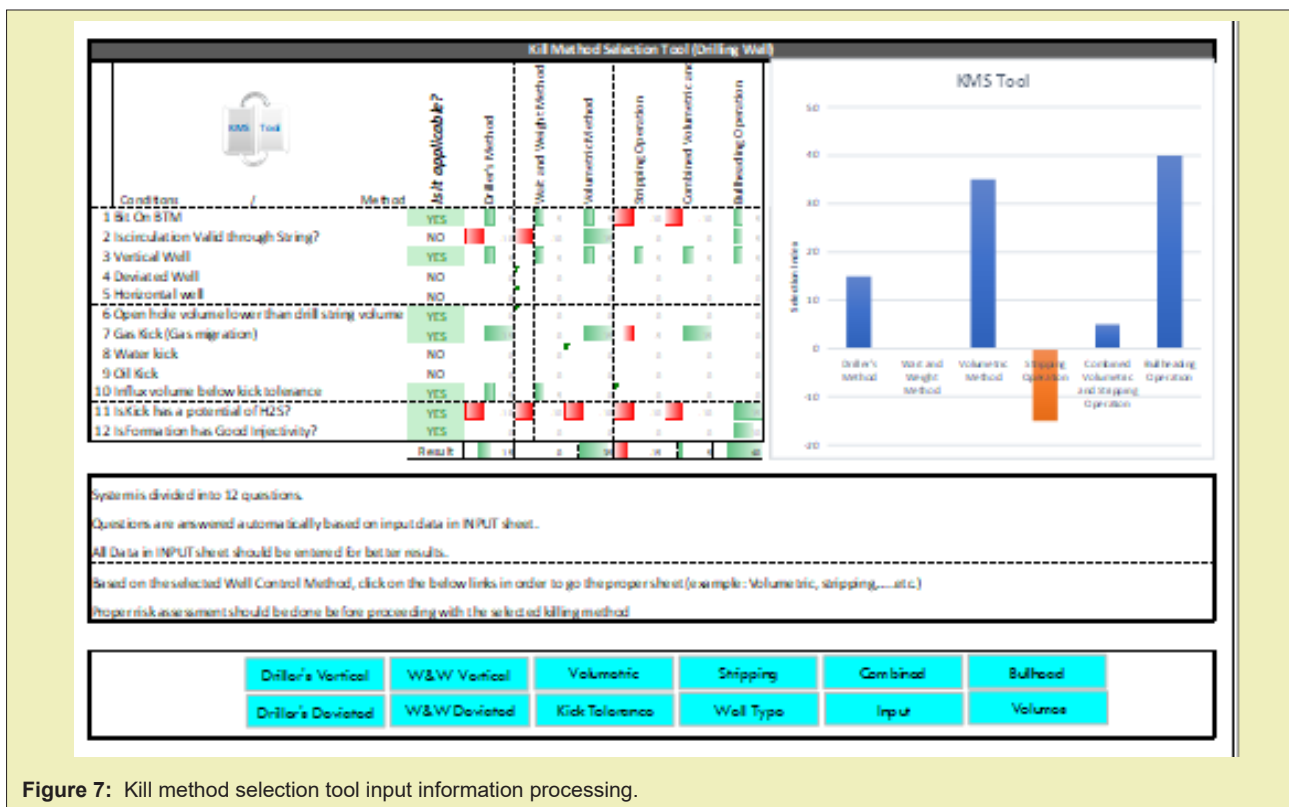


Figure 7: Kill method selection tool input information processing.

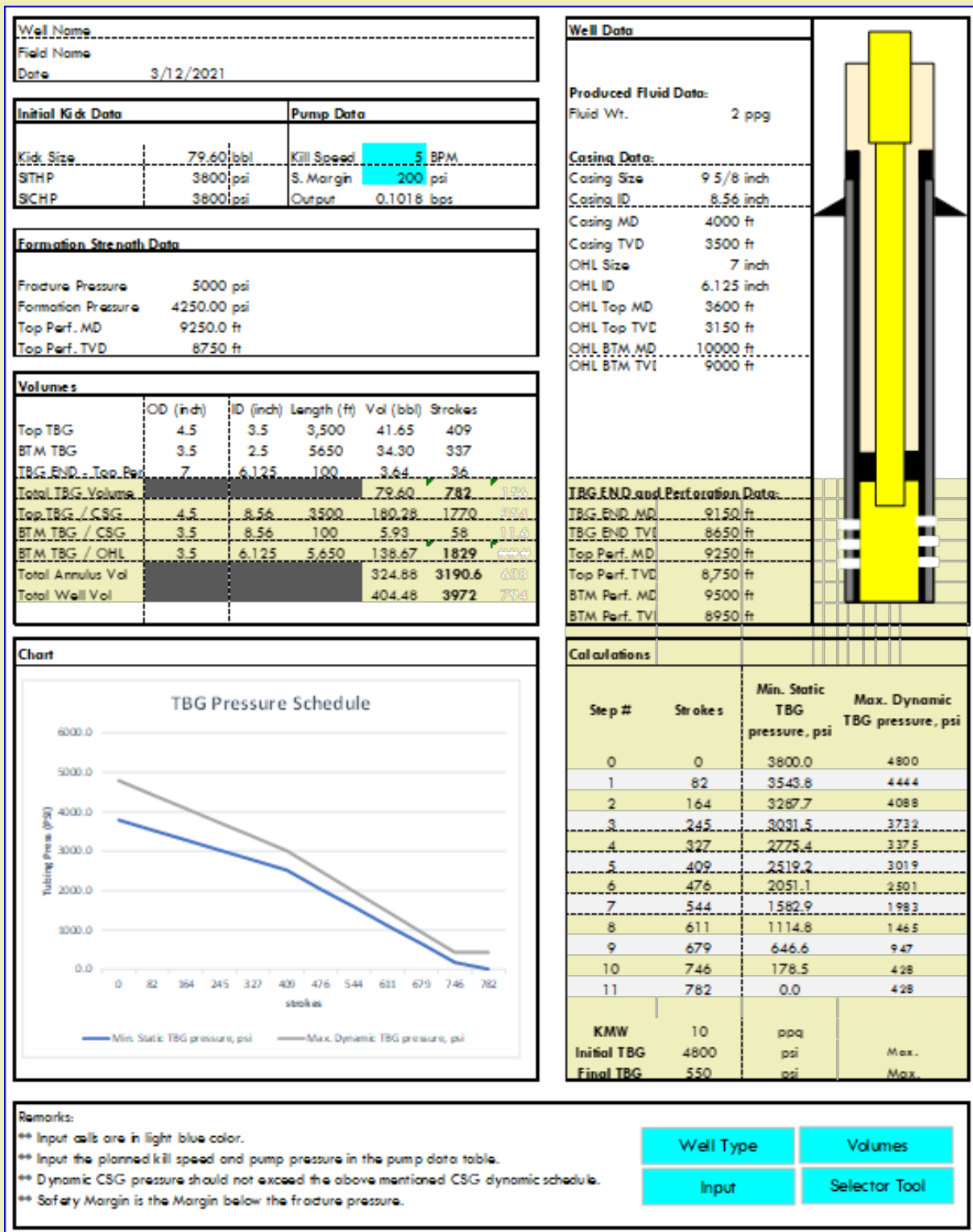


Figure 8: Bullhead calculations' output from the kill program selector.

These data were applied on the Drilling and Well Control simulator. The kill sheet of the well is shown in Figure 12 where well

data and well drawing, formation pressure strength, volumes, drill pipe schedule and pump strokes table are give on one sheet.

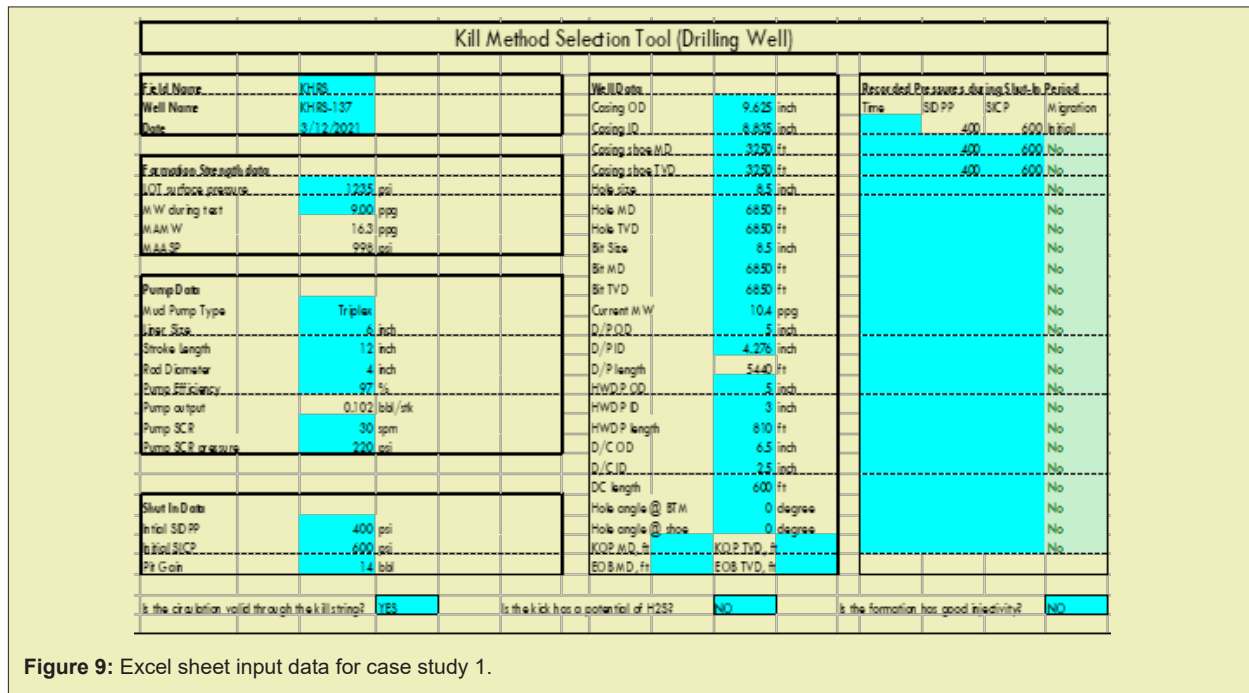


Figure 9: Excel sheet input data for case study 1.

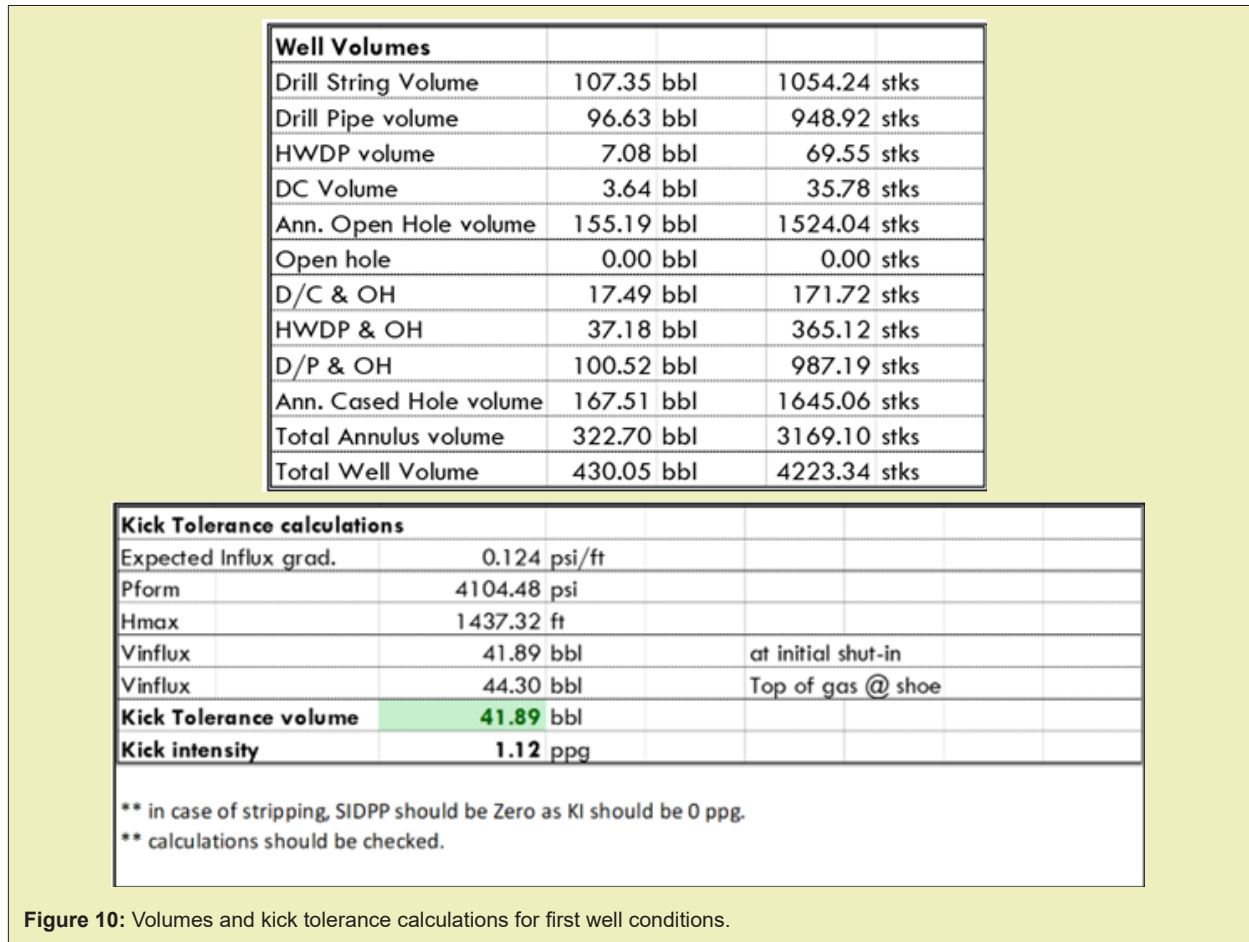
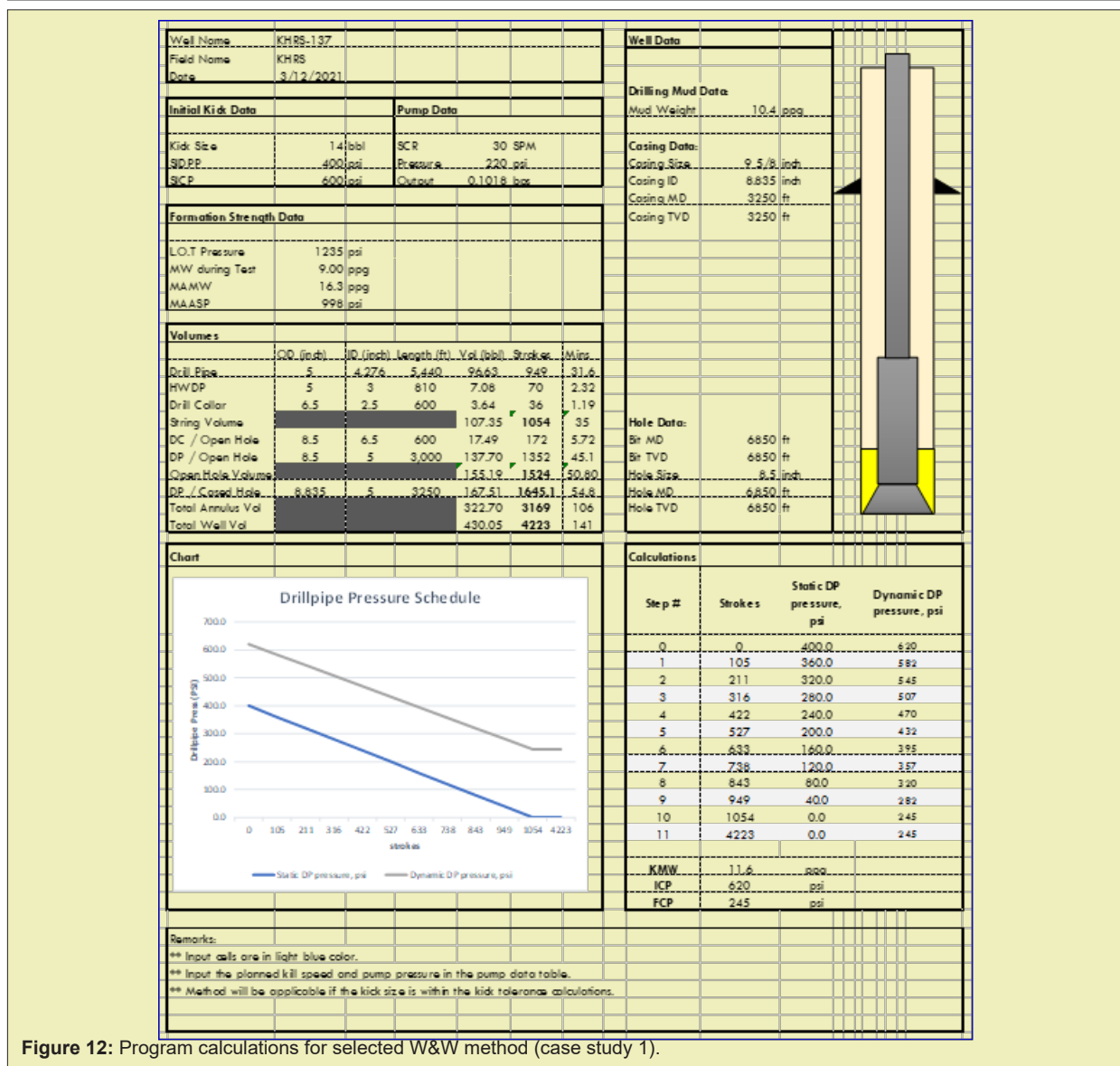
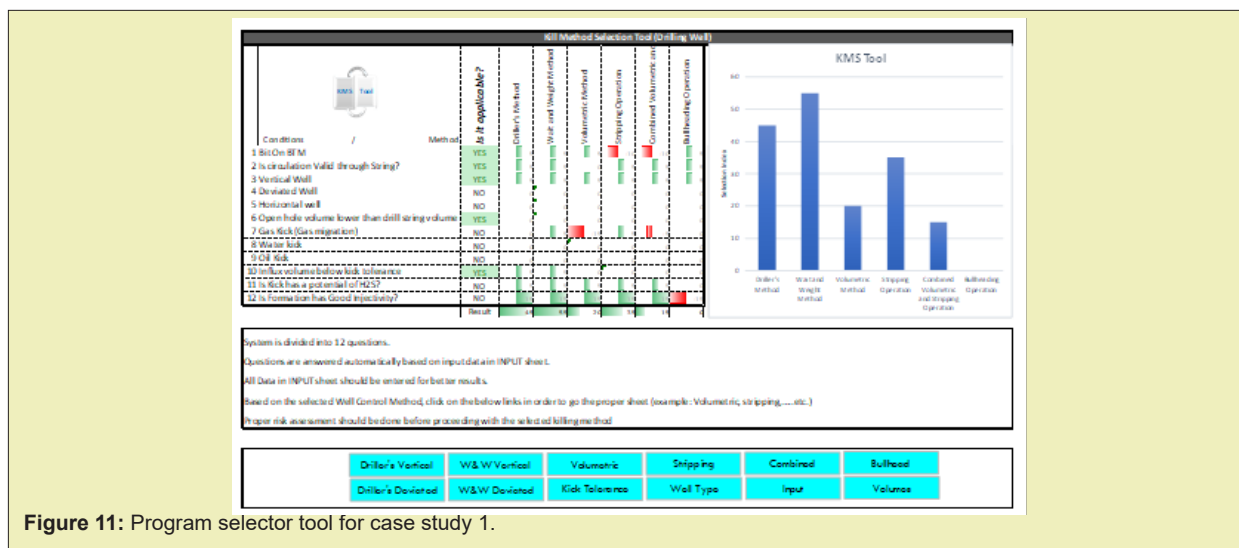


Figure 10: Volumes and kick tolerance calculations for first well conditions.



Case study 2

The second well conditions were inserted in the program as shown in Figure 13. The well was drilled to 6,850ft MD/TVD. The 9-5/8" casing was run and cemented at 3,250ft MD/TVD. A kick was observed during the drilling 8-1/2" hole using 10.1ppg mud. The well has been shut-In and the surface pressures were recorded. Gas migration was recorded. The well was vertical. It was recorded from the offsets that there was no potential of H₂S gas during kill operation.

From the program kick tolerance calculations, the recorded kick size was within the kick tolerance volume as shown in Figure 14. The maximum allowable kick size before the casing shoe breakdown was 39 barrels and the kick size was 12 barrels. From the se-

lector tool, the system recommended to use the volumetric method as shown in Figure 15 and this was shown in the graph that shows the highest Selection Index.

The output calculations of the kill sheet shown Figure 16, were applied during killing the well on the simulator as shown in Figure 4,10 and Table 4,2. A safety margin of 50psi and a working pressure of 50psi were used. The SICP was allowed to increase from 690psi to 790psi (SICP plus Safety margin and working pressure) by allowing the gas to migrate. The next step was to allow the gas to expand by bleeding a 4.9bbl mud equivalent to 50psi working pressure while maintaining the SICP pressure constant at 790psi. The next step was to let the casing pressure to increase by working pressure then bled 4.9bbl mud maintaining the casing pressure constant and continue with the same steps until the gas approached surface.

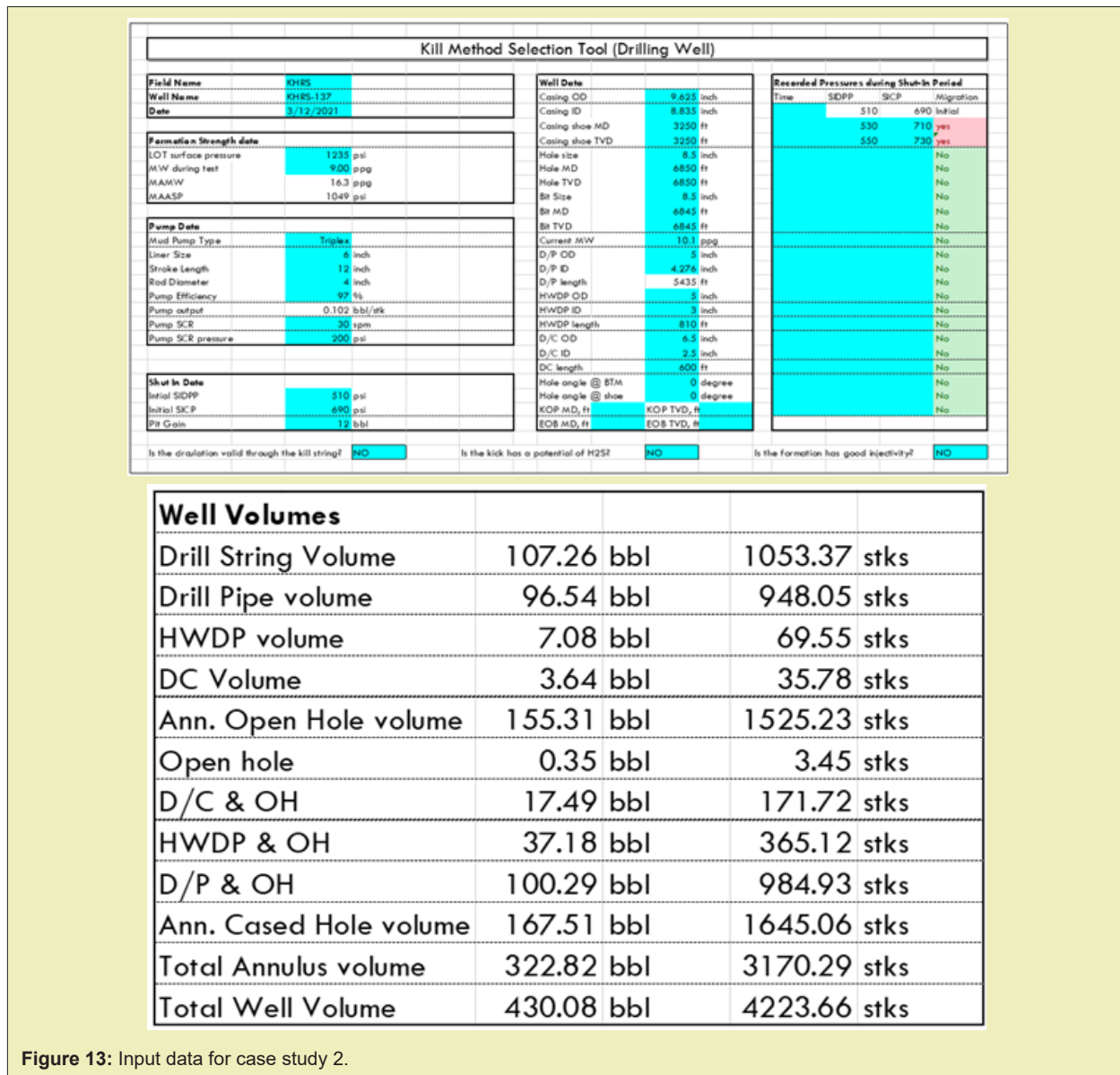


Figure 13: Input data for case study 2.

Kick Tolerance calculations			
Expected Influx grad.	0.088	psi/ft	
Pform	4107.6	psi	
Hmax	1233.22	ft	
Vinflux	35.94	bbl	at initial shut-in
Vinflux	37.98	bbl	Top of gas @ shoe
Kick Tolerance volume	35.94	bbl	
Kick intensity	1.43	ppg	

Figure 14: Volumes and kick tolerance calculations for second case study.

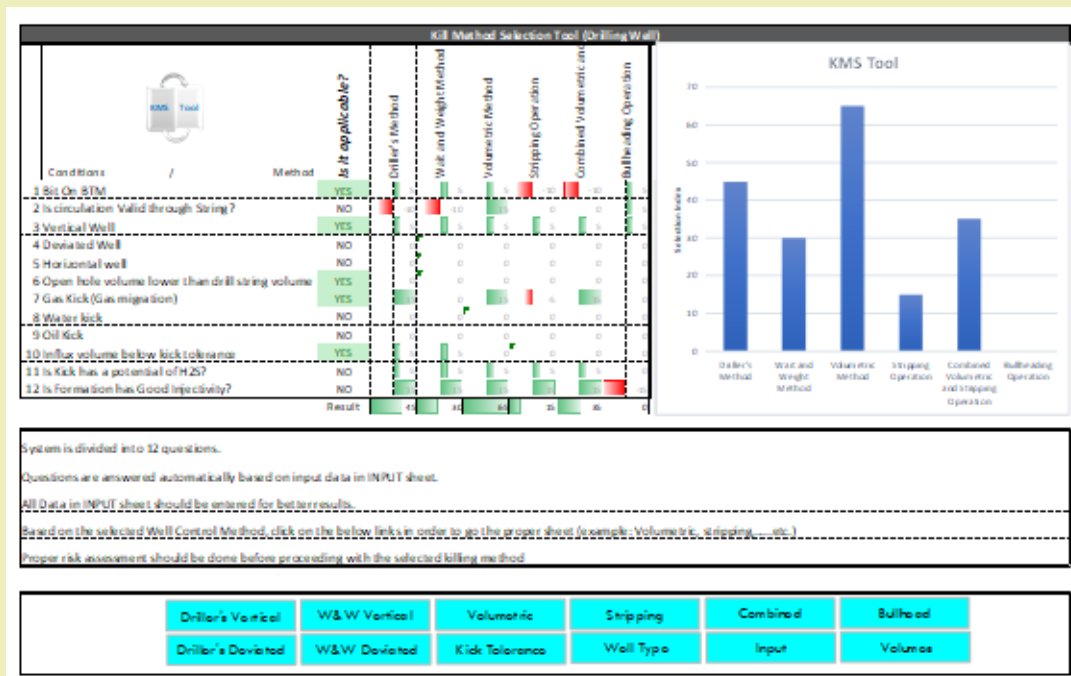


Figure 15: Program selector tool for case study 2.

The gas is migrated and expanded safely to surface without any complications related the calculations as shown in the kill sheet.

Since volumetric method allows gas kick to migrated and expanded under controlled condition to approach surface, lubricate and bleed method has to be used was used to replace the gas with mud. The program generates a kill sheet for lubricate and bleed method to replace the gas in the well with kill mud, Figure 17.

The program is easy to work with and the results are generated quickly avoiding the wrong decision of the drilling team.

Conclusion

Based on the results obtained from the study the following conclusions are reached:

- Selection criteria for well control methods for both drilling and producing wells are justified based on 12 questions for drilling well and 8 questions for producing well.

- Weighted average for each criteria is given based on 200 well data.
- Excel sheet program is built to select the optimum kill method for drilling or producing wells based on the answers to the selection criteria questions.
- Questions are set as well as input data are identified to be given in the program.
- Based on the input data and the answers, an excel sheet process the data and worked it out, then the optimum kill method is identified through a bar chart.
- Program output give a kill sheet and a kill data for the selected optimum kill method.
- Many runs for the program are processed for the selection of different kill methods.

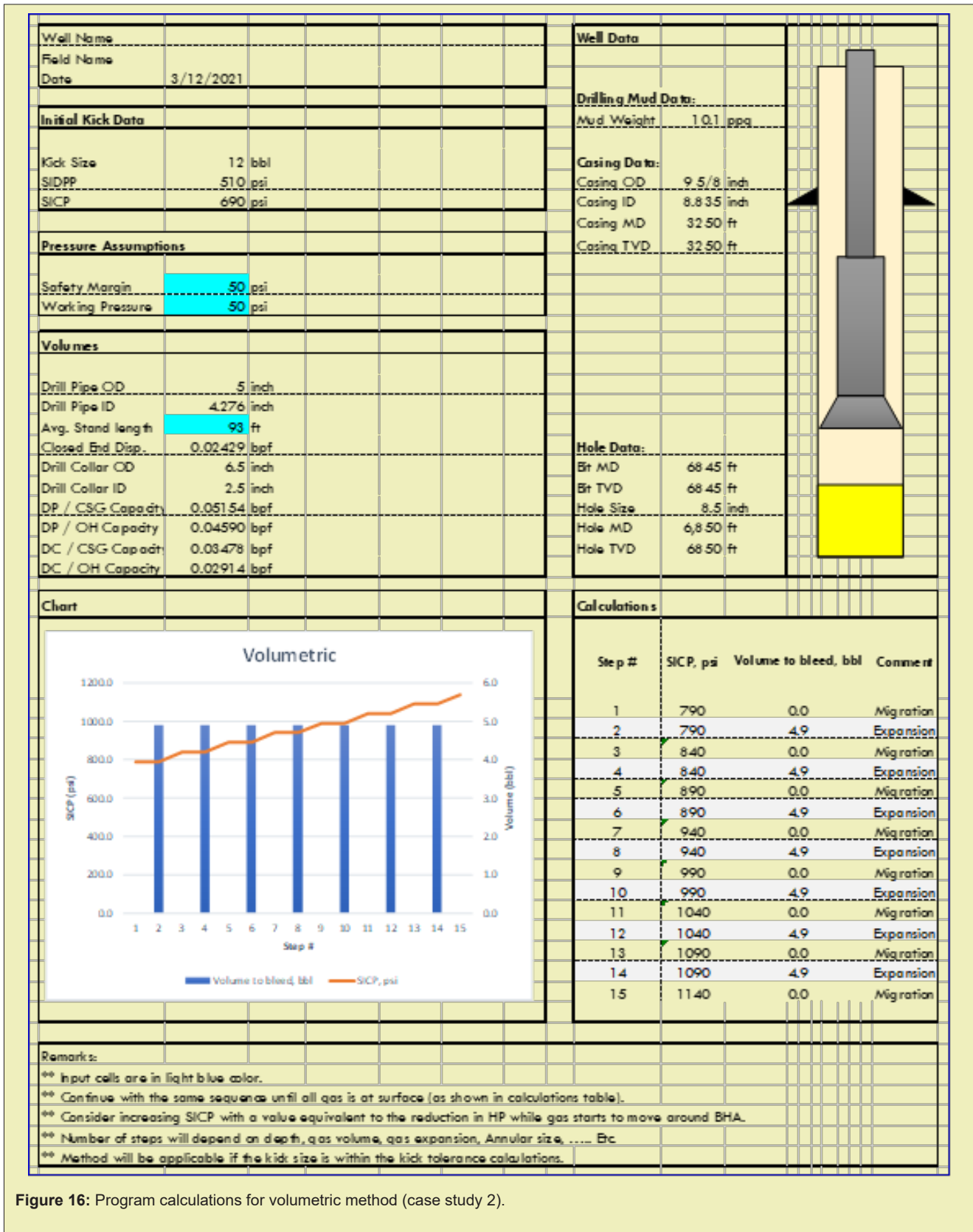


Figure 16: Program calculations for volumetric method (case study 2).

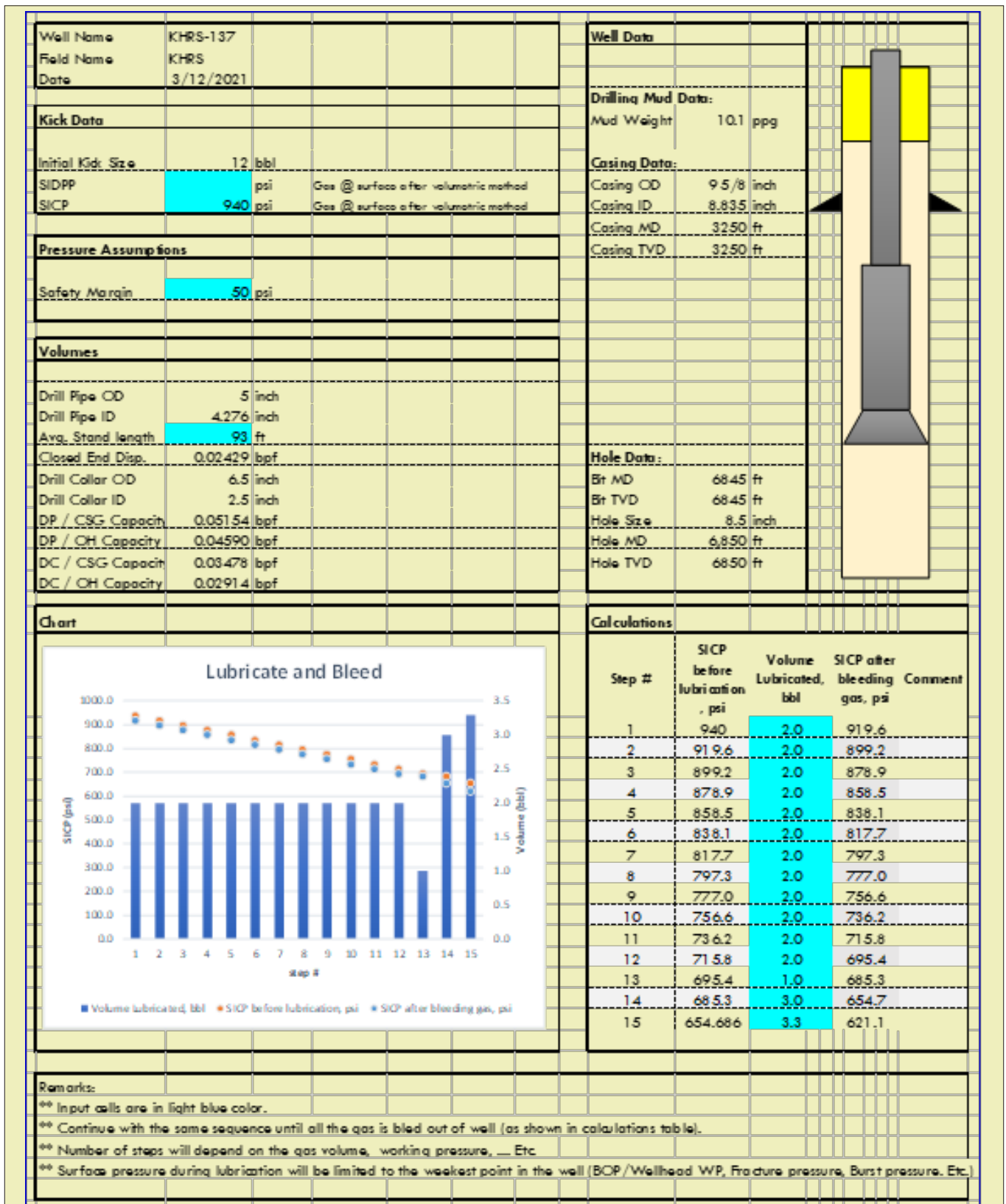


Figure 17: Kill sheet calculations for lubricate & bleed method (case study 2).

Nomenclatures

$C_{DP\&OH}$	Annular capacity between drillpipe and open hole, bbl/ft
$C_{BHA\&OH}$	Annular capacity between BHA and open hole, bbl/ft
FCP	Final Circulation Pressure, psi
FG	Fracture Gradient, psi/ft
ICP	Initial Circulation Pressure, psi
IG	Influx gradient, psi/ft
K_g	Gas relative permeability, md
L_k	Kick length, ft
L_{max}	Maximum kick length, ft
MAMW	Maximum Allowable Mud Weight, ppg
MASP	Maximum Anticipated Surface Pressure, psi
MG	Mud Gradient, psi/ft
P_1	Formation breakdown pressure at shoe, psi
P_2	Formation pressure, psi
P_{SCR}	Dynamic pressure loss at slow circulation rate, psi
P_e	Pore pressure at the drainage radius, psi
P_p	Pore Pressure, psi
P_F	Fracture Pressure, psi
P_h	Hydrostatic Pressure, psi
P_{ch1}	Choke pressure, psi
P_{ann}	Annulus pressure, psi
P_w	Working pressure, psi
P_s	Safety margin, psi
P_s	Applied surface pressure during LOT, psi
P_{wf}	Pore Pressure at the wellbore, psi
P_{Shoe}	Casing shoe pressure, psi
q_{gsc}	Drilled gas entry rate, scf/min
R	Gas constant
r_e	Drainage radius, ft
r_w	Wellbore radius, ft
stk	Strokes
T_z	Bottomhole temperature, °F
V_1	Kick volume at casing shoe, bbl

V_2	Kick volume at initial shut in, bbl
V_k	Kick volume, bbl
Z	Gas compressibility factor
$\Delta P / 100$ STK	Drill String pressure schedule, psi/100 stk
ρ_{influx}	Influx gradient, psi/ft
ρ_m	Mud gradient, psi/ft
μ_g	Gas viscosity, cp

Acknowledgment

None.

Funding

None.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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