Pegasus Vertex, Inc.

Drilling Software | Sophisticated Yet Simple

WHITE PAPER

Surge Pressure Prediction for Running Liners

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Moving a drilling string (or casing or liner) is accompanied by a displacement of the mud in the hole, leading to pressure variations. A pressure increase due to a downward pipe movement is called surge pressure, whereas, the pressure decrease due to an upward pipe movement is called swab pressure.

Excessive swab pressures may initiate a kick, while surge pressures are detrimental in that they frequently are of magnitude large enough to fracture a formation. This is particularly true for ERD wells, slim hole and deep water offshore drilling because of restricted flow paths and limited number of casing and liners. The accurate prediction of surge and swab pressures is of great importance in wells where the pressure must be maintained within narrow limits to ensure trouble-free drilling and completion operation.

I. Introduction

New drilling and completion technologies are challenging many aspects of our operations. For example, running liners in subsea casing string with very tight tolerance can cause extremely high surge pressures. Auto fill float equipment and other new tools such as flow diverter (also called circulation sub) have been developed to reduce the surge pressure and they do show improvement. Questions are: what will be the surge/swab pressures or what are the optimal tripping speeds?

To thoroughly analyze surge pressure, a comprehensive surge and swab hydraulics computer model SurgeMOD has been developed to assist in analysis and design of tripping operations; especially for deep water wells or wells using new tools such as auto-fill float equipment, circulation sub, etc. The program simulates fairly complex wellbore configurations including multiple pipe sizes, wellbore intervals and annular sections with very tight tolerance.

This article will review the engineering analysis behind trip operations for different pipe end conditions: (1) closed, (2) open, (3) open w/ auto fill or bit, (4) with flow diverter. These 4 conditions are illustrated in Figure 1. The author will discuss the controlling parameters affecting surge pressure using SurgeMOD. There are 2 aspects of the surge and swab pressure analysis: one is to predict surge and swab pressure for a given running speed (analysis mode), while the other one is to calculate optimal trip speeds at different string depths without breaking down formations or causing a kick at weak zone (design mode). This article will address both issues. Examples of running liners in tight tolerance wellbore will be analyzed.

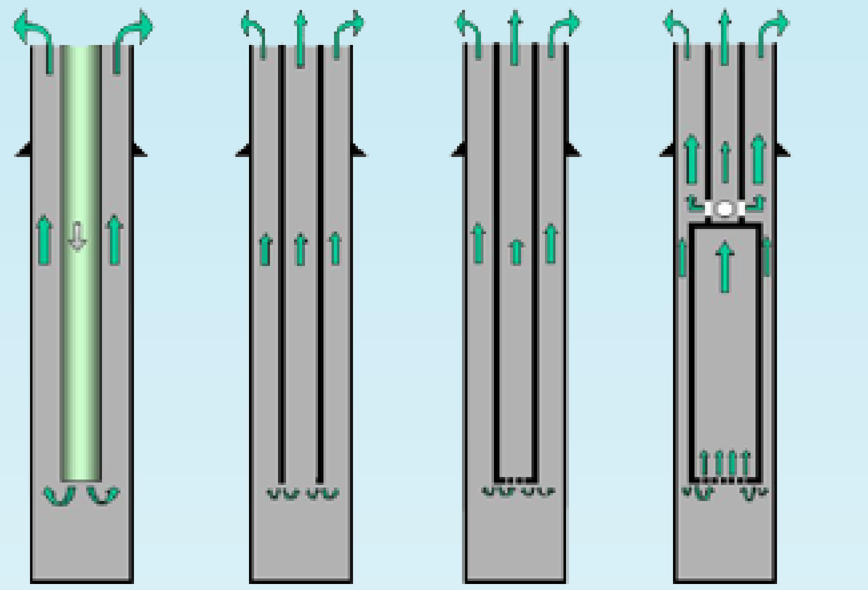


Fig. 1. Pipe end conditions

Closed Pipe

As pipe is moved downward into a well, the original mud is displaced by the new volume of the extending pipe and the mud must move upward. When the pipe is closed or contains a float sub, all displaced fluid passes up the annulus. Flow rate in annulus is equal to pipe displacement rate. It is therefore easy to calculate the frictional pressure drop in the annulus. Surge pressure is calculated using standard hydraulics equations. However, the equations have to be modified to account for movement of the pipe wall.

Fully Open Pipe

If the pipe is open-ended, the problem is getting more complicated since the distribution of flow between inside pipe and annulus cannot be determined by any simple method. A split of flow going to the annulus and pipe interior is iteratively calculated. A numerical method must be used to make sure that the summation of resulting frictional pressure drops inside the pipes is equal to that of all annular sections.

Auto-Fill or Pipe with Nozzle

The difference between auto-fill float equipment and a fully open pipe is due to the additional pressure drop across the orifices on auto-fill float equipment. Depending on the total flow area of auto-fill equipment, the resulting surge pressure can vary significantly. The actual surge pressure should be between those of closed pipe and fully open pipe.

Pipe with Flow Diverter

A new tool, commonly referred to as flow diverter valve or circulation sub, has been developed that is used in conjunction with auto-fill float equipment. This tool, located on drillpipe immediately above the liner, has ports open to the drillpipe annulus. These ports allow the fluid trapped in the liner to escape from the narrow drillpipe interior to the larger annulus between drillpipe and casing. Equipped with this tool, the system now has 2 places of fluid communication between pipe interior and annulus: one at the bottom of the liner (auto-fill float equipment), the other at the top of the liner (circulation sub). Displaced fluid is seeking the least resistant path to flow. This device will help to reduce the surge pressure depending on the wellbore configurations and location of the flow diverter tool.

II. Discussion and Case Study

Surge and swab pressure was studied as early as 1934. Since then, many researchers have used different approaches to predict surge and swab pressures. The most common approaches are using steady flow models, such as those proposed by Burkhardt, Fontenot and Clark, and Schuh. Lubinski, Lal and Mitchell used dynamic models to predict surge pressures. Generally speaking, the steady flow model is conservative in nature and normally does not consider the following 3 factors: (1) fluid compressibility, (2) fluid inertia, (3) pipe longitudinal elasticity. Dynamic surge models, while giving less conservative predictions, are more complex and require not only more input data, which may not be readily available to engineers, but also more computer resources.

In this study, an improved steady flow model SurgeMOD is employed. One of the improvements is the correct calculation of the mud clinging constant. The mud clinging constant represents the proportion of pipe velocity that must be added to fluid velocity in order to find the equivalent or effective velocity that can be used in the stationary annulus calculation. In the oilfield it is a common practice to assume a clinging constant of –0.45; but it is shown that this can be considerably in error. SurgeMOD calculates the correct mud clinging constant based on the ratio of pipe diameter to hole diameter.

Numerical methods are employed to obtain the correct flow split percentage when there are communications between pipe interior and annulus. The flow split is chosen such that the sum of hydrostatic and frictional pressures in the pipe interior and through the bit (auto-fill float equipment) should equal the sum of hydrostatic and frictional pressures in the annulus. Most drillpipe in common usage has an internal upset and a larger OD at each tool joint. SurgeMOD takes into account additional pressure losses caused by tool joint restrictions.

Fig. 2 shows the wellbore configuration used for the example calculation. The riser (ID = 17.755 in.) depth is 3500ft. The casing (ID = 12.715 in.) was set at the depth of 10000 ft. Open hole has a diameter of 14.5 in. The total depth of this vertical well is 15000 ft. The mud weight is 11 ppg with plastic viscosity of 20 cp and yield point of 15 lb/100ft2. The weak zone is at 15000 ft with pore and fracture pressure gradient of 9.5 ppg and 12 ppg, respectively.

Our goal is to run 5500 ft of liner (11 ¾ in OD, 60 lb/ft, 10.772 in. ID) to bottom. The auto-fill float equipment has an orifice with a total flow area (TFA) of 4.91 sq. in. The challenge is to run the liner through the casing and open hole section without fracturing the formation. Note that the annular radial clearance between casing and liner is 0.4825 in.

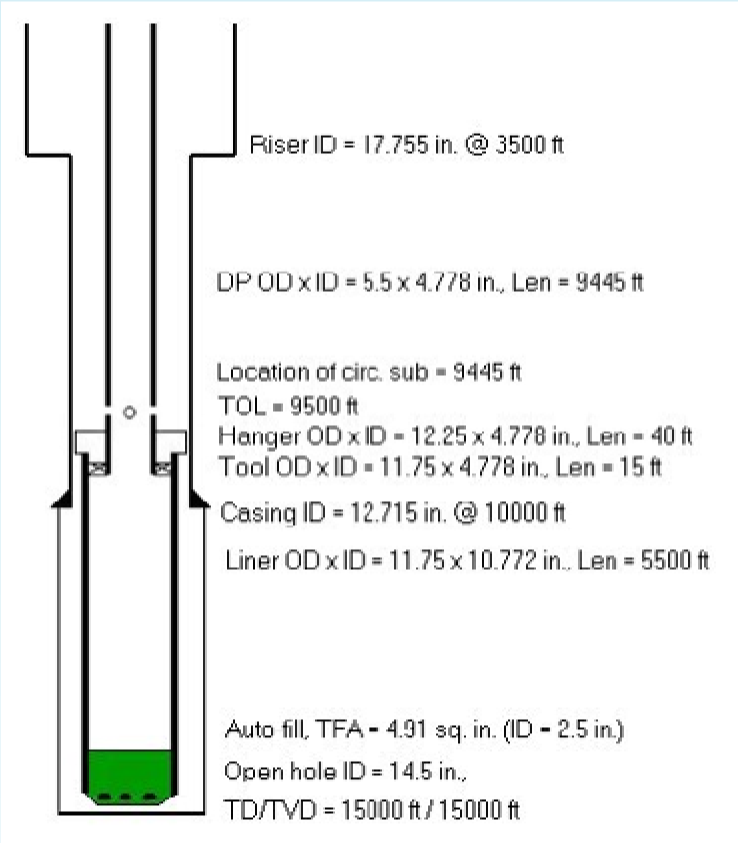


Fig. 2. Wellbore Configuration

Analysis Mode

We will first use the analysis mode of SurgeMOD – calculate surge and swab pressures for a given tripping speed.

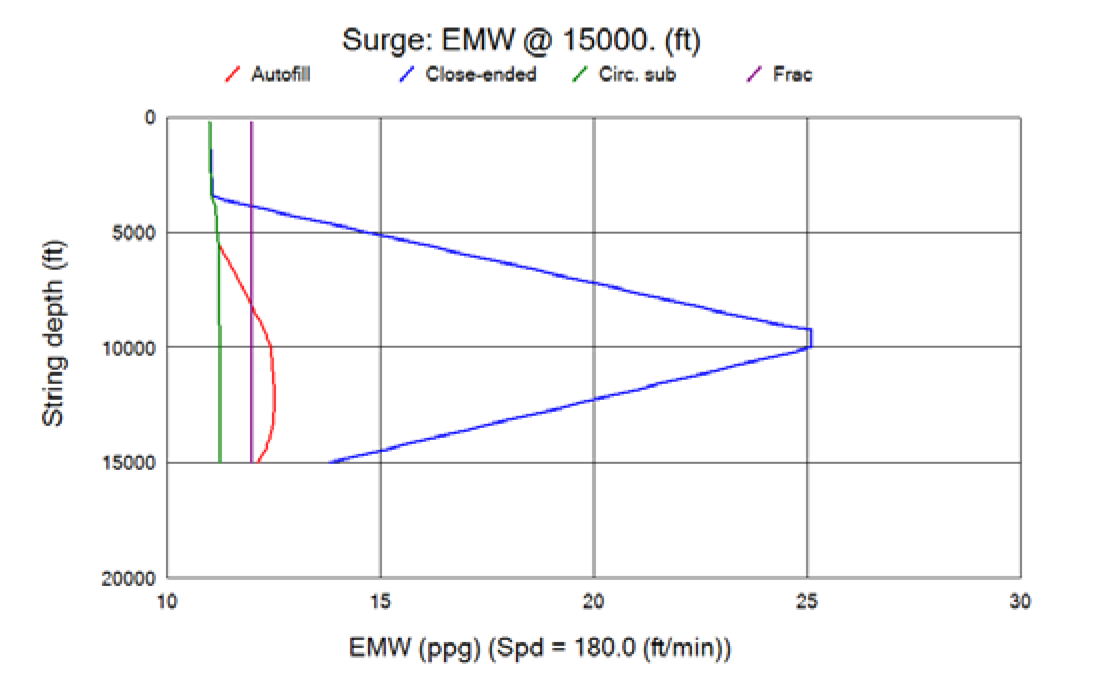


Fig. 3. Bottomhole equivalent mud weight (EMW) vs. liner depth

Fig. 3 shows the simulated bottomhole equivalent mud weight (EMW) vs. liner depth during the trip-in operation at 180 ft/min (3 ft/s). Obviously, if the pipe is closed at the end, the loss of circulation would occur when the liner reaches 4000 ft. For a liner with auto-fill float equipment (TFA = 4.91 sq. in.), it could go as deep as 8400 ft without fracturing the formation. If a circulation sub is placed above the liner, this trip speed would be safe for the entire wellbore. EMWs for both closed and open pipe decrease after the pipe passes 10000 ft due to the larger diameter of the open hole section. We can see that a certain tripping speed may be safe at total depth (TD), but it would have already fractured the formation before it reaches TD.

Design Mode

This naturally brings us to the design mode of the program: it is our desire to predict the optimal tripping speeds at various string depths. Optimal tripping speed is the maximum pipe running speed without fracturing the formation or causing a kick at a weak zone.

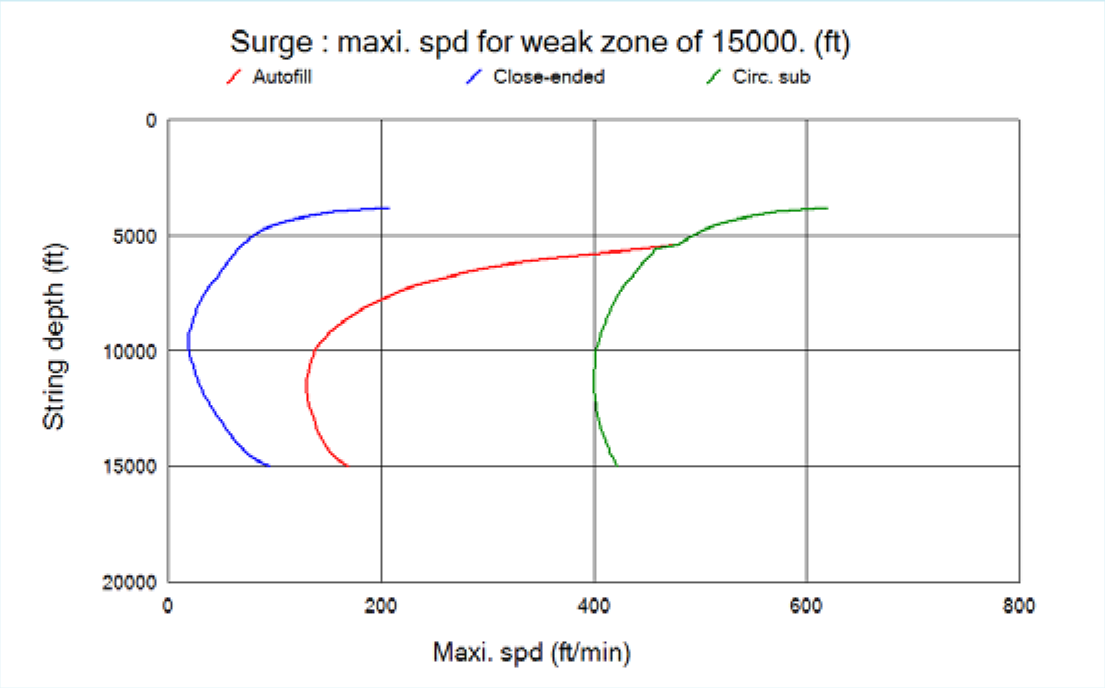


Fig. 4. Optimal trip-in speeds

Fig. 4 shows the optimal tripping speeds for different pipe end conditions at various depths. As we can see from this graph, engineers must pay close attention before the pipe reaches 10000 ft. At 10000 ft, the narrowest annular section is the longest, therefore producing the maximum surge pressure. When the liner enters the larger open hole section, trip speeds can be increased. The most dangerous string depth is not necessarily at the bottom of the well. Note also that the curves for pipe with auto-fill float equipment (labeled “nozzle” in Fig. 4) and pipe with a circulation sub coincide above string depth of 5555 ft. This is because above that depth, the circulation sub, which is located at depth of 9445 ft, is not in to the well.

Sensitivity Analysis

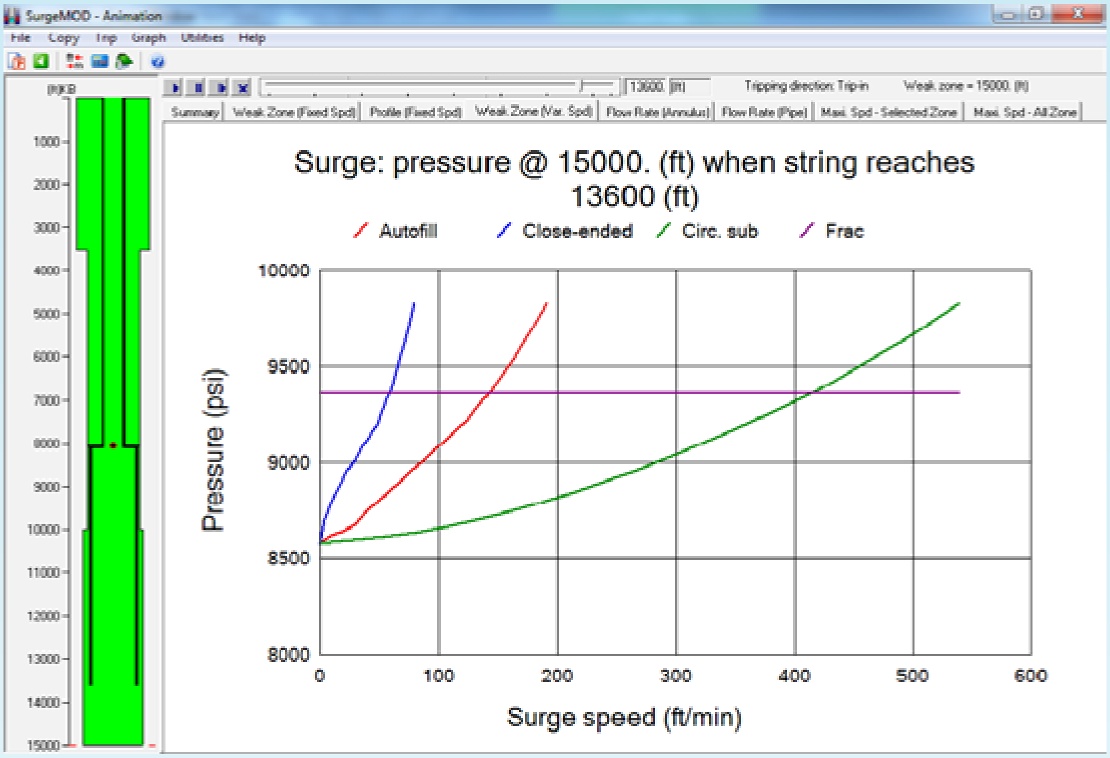


Fig. 5. Sensitivity of surge pressures to tripping speeds

Fig. 5 shows the sensitivities of surge pressures to tripping speeds for the following pipe ending conditions: (1) closed, (2) open w/ auto fill float equipment or bit, (3) with flow diverter. SurgeMOD program is equipped with pipe moving animation so the user can view the positions of the pipe and pressure variation simultaneously. Fig. 5 is for the sensitivity of surge pressures at depth of 13600 ft. As we increase the tripping speed, the surge pressure for closed pipe increases sharply and one for the pipe with a circulation sub gradually increases. The curve for the pipe with auto-fill float equipment lies between them.

Effects of Total Flow Area (TFA) of Auto-Fill Float Equipment

We have realized that the pipe ending conditions have great effects on surge pressures. Now we would like to see how the total flow area of auto-fill float equipment affects the surge pressure for open-ended pipes.

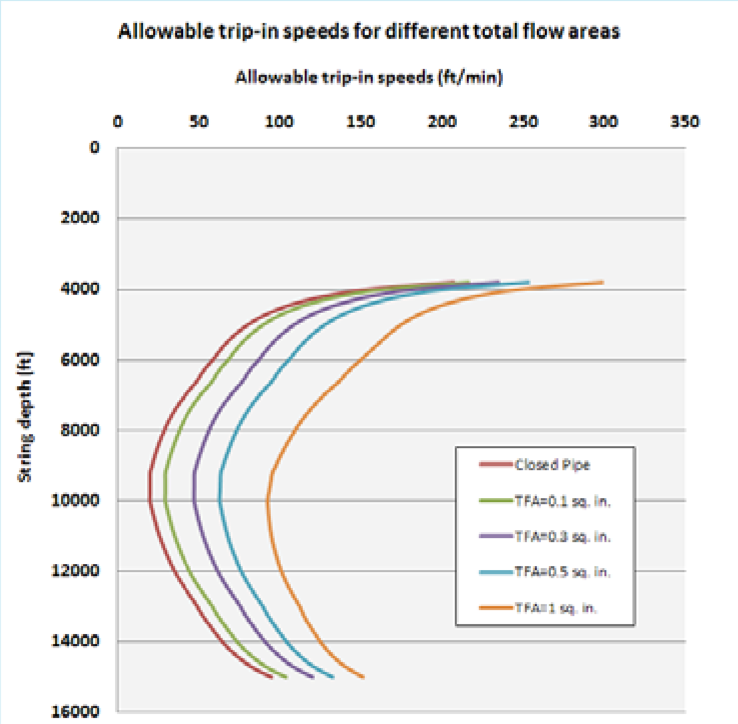


Fig. 6. Effects of total flow area (TFA) of auto-fill – trip in speed

Fig. 6 shows the optimal trip-in speeds vs. string depths for various TFAs. As the TFA of auto-fill float equipment increases, the optimal trip-in speed curve shifts to the right, allowing greater trip-in speed. The reason for this shifting is that the large TFA allows the fluid to move in to the pipe interior more freely, reducing the amount of fluid flowing into the annulus. This redistribution of flow reduces the overall frictional pressure drop along the flow paths inside the pipe and outside in the annulus.

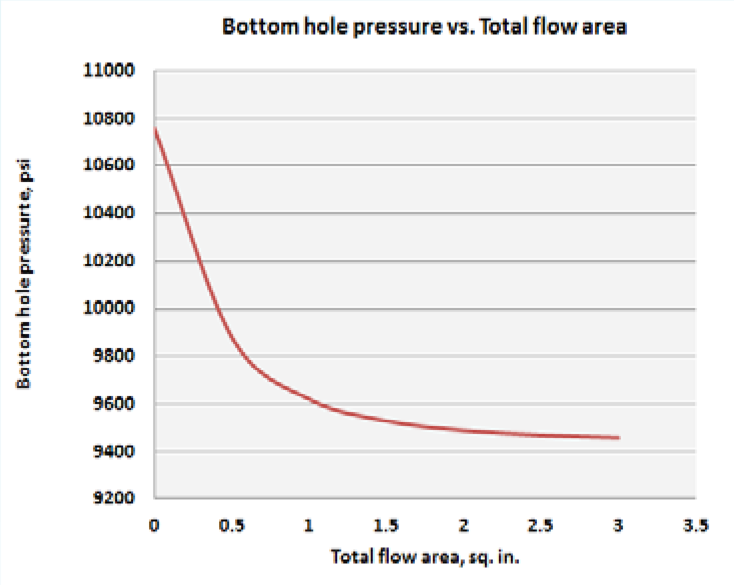
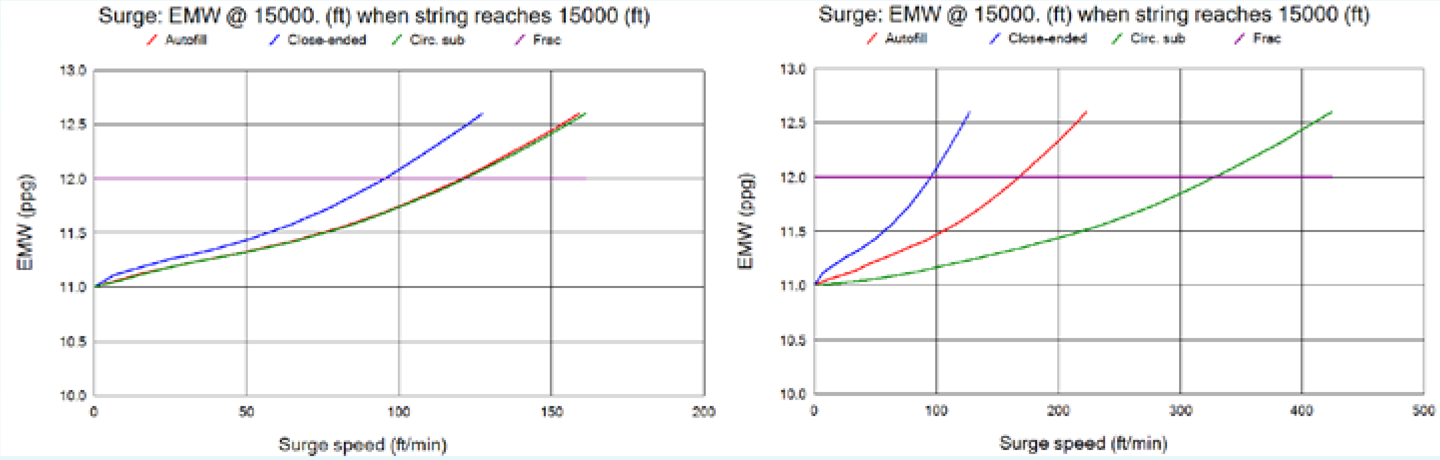


Fig. 7. Effects of total flow area (TFA) of auto-fill – BHP

Fig. 7 shows the influence of TFA on the bottom hole surge pressure. Zero TFA corresponds to closed pipe. The sharp surge pressure drop, accompanying the TFA increase, results from the redistribution of flow between the pipe interior and the annulus. Between closed pipe and TFA of 1 sq. in., the increase of TFA improves the surge pressure significantly. However, for the case shown, TFA greater than 2 sq. in. reduces the bottom hole surge pressure marginally.

Nevertheless, the TFA of auto-fill float equipment is very important if it is used in conjunction with a circulation sub. Fig. 8 compares the situations with 2 TFAs. Fig. 8A is the simulated results of a case with TFA of 0.3 sq. in., while Fig. 8B with TFA of 3 sq. in. Here, the TFA of 0.3 sq. in. represents either improper design of auto-fill float equipment or auto-fill equipment obstructed by cuttings. The advantages of a circulation sub with auto-fill float equipment having a large TFA, as shown in Fig. 8B, do not show up in Fig. 8A where the auto-fill float equipment TFA is only 0.3 sq. in. This is not surprising, because if the fluid were restricted at the entrance of the liner, the circulation sub at the top of the liner would not be able to divert enough fluid into the annulus. Therefore, the benefits of circulation sub depend on the sufficient TFA of auto-fill float equipment. New generation of auto-fill float equipment is available with TFA of 10 sq. in. TFA of this magnitude helps to insure sufficient flow area to reduce the possibility of plugging with formation cuttings.



(A) TFA = 0.3 sq. in.
(B) TFA = 3 sq. in.

Fig. 8. Effects of TFA of auto-fill on surge pressures sensitivity

III. Conclusions

Following are conclusions regarding the engineering analysis of surge pressure:

- An accurate mathematical model to predict surge pressure is of great importance because of the effects of surge pressure on operational safety and success.
- New technologies such as ERD, deep water wells and tools are more complex than conventional drilling and require more thorough surge pressure analysis.
- The maximum surge pressure may occur before pipe reaches bottom hole.
- Pipe ending conditions affect surge pressure significantly.
- A circulation sub improves surge pressure if auto-fill float equipment is properly designed with proper TFA and free of cuttings obstructing auto-fill float equipment.
- Properly designed auto-fill float equipment with large TFA reduces surge pressure.
- By running a computer model, engineers can identify potential surge problem and optimize tripping operations for different scenarios and tools.
- Software usage allows engineers to avoid loss of circulation or kick and result in a higher percentage of successful casing/liner runs and other tripping operations, particularly in ERD, slim holes and deep offshore wells.

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