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Review Article

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A Comprehensive Review for Swab and Surge Pressures in Oil Wells

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Abstract

Surge pressure is the additional pressure created when pipes move downward, and swab pressure is the pressure reduction that occurs when pipes move upward. When pipes are raised, it can result in a decrease in the pressure at the bottom of the hole due to the influence of pressure. An investigation showed that surge pressure is important for the circulation loss problem produced by unstable processes in Management Pressure Drilling (MPD) actions. Trip margin is an increase of mud density for providing overbalance so as to recompense the swabbing effect through pulling out the pipes of hole. Through trip margin there is an increase in the hydrostatic pressure of mud that compensates for the reduction of bottom pressure due to stop pumping and/or swabbing effect while pulling pipe out of hole. This overview shows suggested mathematical/numerical models for simulating surge pressure problem inside the wellbore with adjustable cross-section parts. To run the analyzed models, input data such as fluid speed around the drill pipe, pipe movement speed, hole diameter, drill pipe diameter, and internal drill pipe diameter are required. These data can be obtained from the drilling rig website. Swab pressures and surge pressures have been the primary causes of wellbore instability and blowouts in the oil industry for many years, resulting in pressure changes. This review focused on the most important basic theories for calculating the optimal factors related to surge and swab pressures and then linking them to the most important programs for calculating them. One of the most important conclusions from this review is that the optimal speed must be determined for the lowering and raising of pipes, to prevent kick or losses.

Keywords: Swab and surge, Tripping, Drilling, Drill pipe, Oil wells.

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1. Introduction

The surge pressure is created through mud movement because of the string moving inside the well that filled with mud [1]. The swab pressure caused by fluids movement which caused by drill pipes and bottom hole assembly (BHA) that pulled out of well which filled with drilling fluid. It is generally clear that the process of withdrawing and operating the tube can cause a pressure rise [2]. Surge and swab pressure is very documented matter through drilling operations because it is related to the nonproductive time (NPT) if the right procedure not implemented. In the region of the studies that applied the quantitative techniques for guessing the pressure differences downhole accounting for just the drag and viscous immobile pipe wall for Newtonian fluids for the both flow regimes, laminar and turbulent [3]. The approaches which used for quantifying these pressures are alike to these that used for calculating pressure losses through normal circulation mud [4]. To reduce the difficulties of calculations, surge pressure is designed by determining the value of swab pressure and then assuming that this pressure which equal to the value of surge pressure when using the similar speed pipes movement and devices [5]. Values of the surge and swab pressures are too important because further than 25% of the incidents cases are as a result of decreasing the pressure in the well directly to the case of the swab through pipes withdrawing, furthermore, high values of swab pressures may cause losing the drilling mud circulation through the drilling operations of the well [6]. If the pipes running down into the well, the mud may move up and likewise when the pipes pull out pf hole, the mud will move downwards [7]. Many differential equations which describe the laminar flow through the circular tubes are used for predicting the movement of tubes inside fluids [8]. As a final point, it is probable to derive surge pressure equation for the non-Newtonian fluids by using power law model or plastic Bingham model, wherever the equations are obtained by altering the boundary circumstances on the wall of the well [9].

Table 1 shows the most important studies related to the swab and surge pressures, starting from 1934 to 2021. Where this literary presentation shows the clear progress in the subject of surge and swab pressures, which started from experimental equations and simple calculations and reached to this day to models, equations and prediction, which facilitates a lot and prevents many problems during drilling. The theoretical investigation and experimental consequences established that the surge pressure is a function of the: well depth, combination of the drilling equipment's, wellbore diameter, drilling fluid properties, drill pipe speed and finally the acceleration movement of drill pipe. This review aims to shed light on the most important factors affecting the pressure of swab and surge, in addition to studying and analyzing the models used for prediction and calculating the values of the two pressures above. This review also covers the various mathematical formulas used to calculate the pressures of surge and swab, in addition to specifying the limitations and advantages of each method.

Table 1. previous studies related to the swab and surge pressures.

Researchers	Year	Findings, study, technique, method or model
Cannon	1934	Noticed as a possible cause of outflow into the wellbore. Cannon reflected the problems by way of "a likely reasons of the fluid influx, and dangerous conditions of the blowouts [10].
Goins	1951	Connected the increased in pressures with lost circulation. The surge and swab pressures are reasons a variation in the value of hole pressure, following in to the extraordinary pressure [11].
Lubinski	1977	Established completely dynamic unsteady-state model for the surge and swab pressure. He confirmed the transient motion of the drill string and the surge /swab pressure may be happened because of altercation of the drill string [12].
Mitchell	1988	Recommended a dynamic swab/surge pressure model, richest technology at that time was related with the following: annulus pressure, the elasticity of the pipe; flexibility of longitudinal pipes, the viscosity of fluids, and finally the properties of drilling mud [13].
Nygaard et al	2007	Establish a new technique for coordinated control of the pump rates and the choke valve for compensating the surge pressure value through tripping operations [14].
Fedevjcyk et al.	2009	Examined that wellbore diameter change and using of drill pipe accessories lead to cause changes for the annular cross-section space between the borehole and pipe which have an effect of surge pressure [15].
Crespo and Ahmed	2013	Described the results of an experimental work aimed for investigating the effects of mud properties, drill pipe speed, and wellbore geometry on value of surge pressures under the laboratory conditions [16].
Barrdhard	2014	Provided a relationship for the adhesion constant of bentonite, that helped to derive all these annular space relations for the surrounding circular pipes. In order to find the required surge pressure to break the mud gel [17].
Tian et al.	2017	Conducted tests to measure pressure changes with downhole pressure gauges when withdrawing pipes, regarding that the pipe withdrawing entails wellbore pressure reduction and might lead to blow-out accidents. Later, more experiments were conducted, and field data was investigated about surge-swab pressures [18].
Gao et al.	2019	Established the surge-swab pressure model with the theoretical studies, proposing *t* graph of mud clinging constant for convenient using [19].
Lei et al.	2021	Presented a study on the surge-swab pressure considering in his consideration the effect of the cutting plug-in shale formation [20].

2. Swab surge pressure, concept and mechanisms

2.1. Definition and explanation of swab surge pressure

They are describing the pressure changes in the annulus caused by the movement of the tubes. Sweeping occurs when the drill pipe is pulled out of the well, which will force mud to flow down the annulus to fill the space left by the pipe. But the rise occurs when the drill pipe is lowered into the well, and then the mud is pushed out of the flow line. The pressure changes caused by lowering the tube into the well are called burst pressures and are generally considered additive to the hydrostatic pressure. In this article, we will deal with the smear and surge risks of drilling and its calculations.

2.2. Swab surge pressure generation mechanisms

On the whole, swab and surge pressures relaying on the tripping speed of the drill pipe, the wellbore geometry, flow regimes, fluid rheology, and the pipe case whether is close or open. Numerous flow phenomena, counting pipe eccentricity, dynamic effects, and geometric irregularities, are contributed to the rise in swab or surge pressures [21].

2.3. Implications of swab surge pressure on drilling operations

The value of surge and swab is very important because of the bellow issues:

1. More than 25% of blowout are a result of pressure reduction in the well resulting directly from the swab state when the pipes are withdrawn.
2. The high surge pressures lead to problems of circulation loss of the drilling fluid during the well drilling process or the process of lowering the casing inside the well.
3. The decrease in pressure due to the withdrawal of the pipes may result in pollution in the drilling fluid as a result of the entry of rock formation fluids into the inside of the well, and this may result in an increase in the processing costs of the drilling mud [22].

3. Influencing factors of swab surge pressure

3.1. Wellbore and formation characteristics

The influence of the surge and swab pressures is more in the vertical than the horizontal wells because of the gravity factor, and the most affected formations are shales and non-cohesive sand layers because they are fragile. The important limits used are the diameter of the well, the outer diameter of the drill pipe, the inner diameter of the drill pipe, the length of the pipe, in addition to the gel resistance of the drilling mud [23].

3.2. Drill string and bottom hole assembly design

It is worth noting that it is important to calculate the speed of lowering and inserting the drill pipes. Drill string reasons a flow for the expatriate fluid and a pressure alteration in the borehole at what time running in or pulling out from the hole. When the string passages upward generates a swab pressure and it generates a surge pressure if transfers downward [24].

3.3. Fluid properties and flow rates

The flow pattern of moving fluids can be either laminar or turbulent flow depending on the speed with which the tube moves inside the well, where it is possible to derive the necessary mathematical equations to calculate the pressure of surge or swab in the case of laminar flow, but in the case of turbulent flow, empirical relationships must be used [25].

3.4. Operational parameters

During the operations of lowering and removing pipes, the points below must be observed:

1. Keep the drilling mud at good condition (mud density greater than formation density).
2. Pull out of hole by reasonable speed calculated with equations explained later in this review.
3. Add lubricant materials and keep good mud hydraulic for preventing bit or bottom hole assembly balled up, which requires additional speed to pull the drill pipe.
4. Add chemical additives for example salts and polymers to avoid shale swelling in water base mud or use the oil base mud, which provides more lubrication and reduced friction and less speed to pull the tube. However, any increase in the speed of drawing the pipe causes the collapse of weak formations such as shale and incoherent sand [26].

3.5. Environmental conditions

The drop in pressure due to the withdrawal of the pipes may result in contamination of the drilling fluid as a result of the entry of the rock formation fluids into the well and this may result in an increase in the environmental aspects and then costs of treating the drilling fluid.

4. Experimental Techniques and Field Measurements

4.1. Laboratory-scale experiments for swab surge pressure investigation

Laboratory tests are carried out by making a miniature well system (down scale) and simulating field conditions. The experimental process consists on the upward or downward movement of the thick wall pipe for example about 8 min measuring the pressure difference at a rate of 30 samples per second. When the pipe movement begin from a resting position, the pressure difference differs as time goes by up to the steadying.

The effects of swab and surge pressures have been recognized since an early age, i.e., since 1934, when Cannon was involved in the eruptions that may happen in normal pressure wells. Although the density of the used mud gave hydrostatic pressures greater than pore pressures of formations, yet the phenomenon of eruption happens in the well [27]. In order to inspect this problem, Cannon showed a series of the experiments in order to quantity the real pressures of extraction and the dates. Table 2 shows Cannon experiments results. It was found that the pressure of surge at a depth of 9000 feet using a mud with a resistance of 39 inside the annular space with a liner diameter of 8 equals 468 lb./in^2 [28].

Table 1. Cannon experiment [28].

Outside diameter (inch)	**Depth (ft)**	**Gel strength (lb/100ft^2)**	**Surge pressure (psi)**
$4^{1/2}$ drilling pipe, $8^{3/4}$ casing size	7100	39	276
	7200	18	128
	3100	39	129
	3300	22	162
$4^{1/2}$ drilling pipe, 7 in casing size	8000	68	427
	9000	35	452
	7000	23	332
	4000	54	252
	5000	39	210
	6000	16	167

4.2. Field measurements and case studies

Many studies tried to clarify the quantitative techniques for predicting pressure differences downhole related for the viscous drag and motionless pipe wall for the Newtonian fluids for both turbulent and laminar flow regimes [29]. Field or documented pressure is frequently unobtainable; nevertheless, few analyses have collected relevant [30]. Figure 3 contains information for confirming the downhole pressure differences. Its shows a schematic diagram of the pressure change measurements inside the well during the lowering of one pipe connection at a depth of about 1850 feet [31].

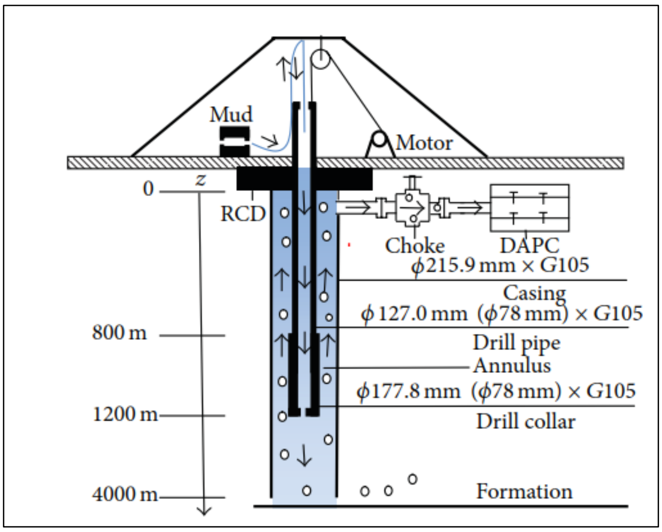

Fig. 3 schematic of gas influx through tripping [31].

4.3. Comparison of experimental techniques

All laboratory experiments in order to measure swab and surge pressures are based on the work of a mini-system for the well (down scale), and the difference lies only in the type of mud and its characteristics, as well as whether the well is vertical, horizontal, or inclined at an angle, depth, the speed of lowering the pipes and the time required for that in addition to the drilling system (open or close). Also, the difference lies in the parameters that are being studied. As it was previously detailed, there are several parameters affecting surge and swab pressures, and it is not possible to study them simultaneously, as researchers study 3 to four parameters and install the rest. For example, Ruchib has studied the effects of various drilling parameters for instance rheology fluids flight velocity, and the number of phases on the swab and surge pressures as shown in Fig. 4. Emily has studied the effect of different diameters and the ability of the drilling fluid to clean the well on the surge and swab pressures and stabilize the rest of the factors, and concluded that the surge and sweep pressures are higher with the increase in the diameter ratio [32]. It means for narrow rings the pressure is more noticeable compared to the swipe and impulse pressures in a wider loop. Therefore, special care must be taken when other sections of the wellbore where the size of the bore and wellbore decreases the depth increases. An increase in fluid yield leads to an increase in blood pressure and wiping pressure. Therefore, it is necessary to well improve the yield stress of the drilling fluid. The actual schematic design of the experimental work is illustrated in Fig. 4. This system consists of the following sections: (1) the hoisting system, (2) the testing section (3) testing mud mixing and storing section and (4) data gathering system.

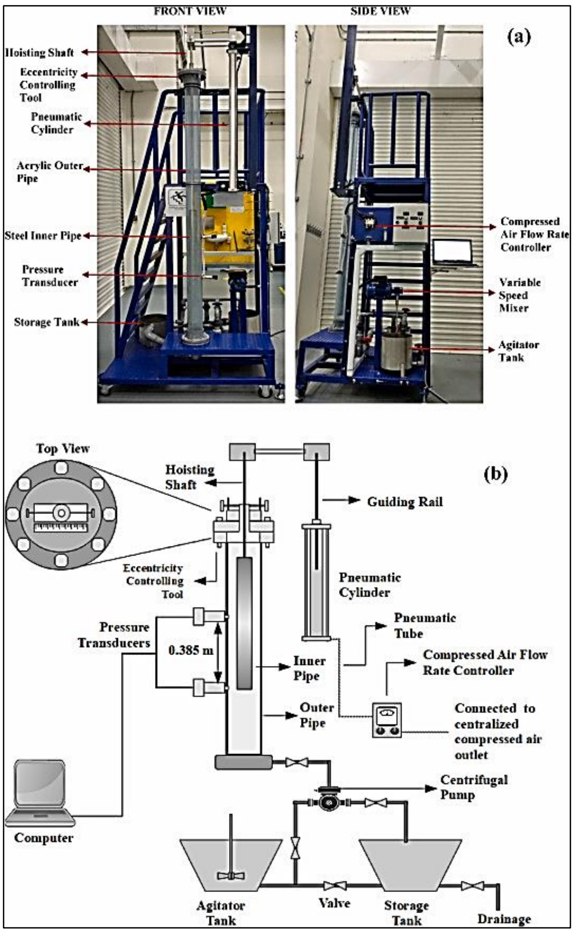

Fig. 4 Experimental measurement (surge and swab pressures) [32].

5. Prediction models and analytical approaches analytical methods for predicting swab surge pressure and numerical simulation techniques

The numerical model is developed by Chukwu [33] for predicting the surge and swab pressures by simulating the downhole pressure variations happening through tripping in wells. Their model uses the current variable narrow-slot guesstimate technique for accounting for the pipe eccentric for surge pressure control. The program created by Microsoft Excel, based program which computes the pressure variations in the well because of surge and swab. The processes of program the input data for checking if the flow is turbulent or laminar [34]. It is desirable to know the calculations carried out by the program, for example, it is possible to observe the pressure change at the lower orifice assembly or the entire system, as shown in Table 3. Where the change of positive or negative pressure is given by the pressure of the new bottom hole [35]. It can be observed that if the new bottom hole pressure is greater than the formation fracture pressure, the following statement will appear that “the wellbore pressure is higher than the formation fracturing pressure”. But in the event that the pressure was within the limits of the fraction, no statement or warning will appear [36], as shown in Table 3.

Table 3. Input fragment for calculating surge and swab pressure [33].

Type	Property	Values	Unit
String	Poisson ratio of string	0.35	-
	Roughness	1.55×10^{-7}	m
	Elastic modulus of string	2.08×10^{11}	Pa
Mud	Dynamic viscosity	0.057	Pa. s
	Density	1461	kg/m^3
Gas	Relative density	0.66	-
	Viscosity	1.15×10^{-5}	Pa. s

Surge and swab are a recognized problem for the drilling operations. Investigators have been examining this problem in many researches [35]. Surge and swab pressures mention to pressure variations because of dropping or retreating the assembly from the hole [36]. Surge and swab pressure variations are may be negative or positive [37]. positive when dropping the pipe down and negative when retreating the pipe up [38]. The strength of those pressure variations be contingent on the lowering down speed in other words, (tripping in) or retreating of the pipe out in other word, (tripping out) as shown in Fig. 6. When the speed of the tripping is too high, the equivalent pressure variation is also high, and may be will higher than the formation fracture pressure [39]. High surge pressure reason for the formation fracturing, but high swab pressure lead to partial or in approximately cases full fluid losses, however for the worst-case situation well collapse may be occurring when the speed is very low, that will lead to a sluggish tripping operation, and that is reflected to the non-productive time (NPT) [40].

Dewitte [41] presented a work to predict the maximum surge and swab pressures, the differences of surge and swab in the time domain at the bottom of the wellbore as in equations (1) to (4). The computer program correspondingly makes cautions influx for the swab or lost circulation for surge.

$$\frac{\partial p}{\partial z} + p\, A\, g\, \partial t + hf\,(q : vp) = 0 \tag{1}$$

$$\frac{\partial p}{\partial t} + s\,\frac{\partial q}{\partial z} = 0 \tag{2}$$

$$S = \frac{Pc}{A} \tag{3}$$

$$c = \frac{g}{\rho(\alpha + \beta)} \tag{4}$$

where:
q: flow rate, bbl/min.
A: cross section area, inch^2.
S: force lb/ft^2.
C: constant.
g: acceleration.
ρ: density ppg.
t: time min.
α , β: constant.
∂p: pressure change.
∂z: depth change.
∂t: time change.
Pc: predicted pressure.

6. Calculation methods and software tools

6.1. Mathematical formulations for swab surge pressure calculations

The basic differential equation (5), that describe laminar flow through circular pipes are used to predict the movement of pipes within fluids and vice versa. The following equation can be used that represents fluid flow inside a pipe [42].

$$\frac{dpf}{dL} = -\mu\,\frac{V}{1500d2} \tag{5}$$

where:
μ = fluid viscosity, *cp*.
V = The average velocity of the fluid in the pipe, m/min.
d = The inner diameter of the pipe, inch.

The effect of the velocity of the drill string on the values of surge and swab pressures is studied by Bourgoyne [43] and as shown in Fig. 5. It is gotten that the high the trip speed means high pressure alteration in the well. Furthermore, pressure variations become fewer sensitive for the tripping speed when the fluid works as shear thinning with lessening the flow behavior index.

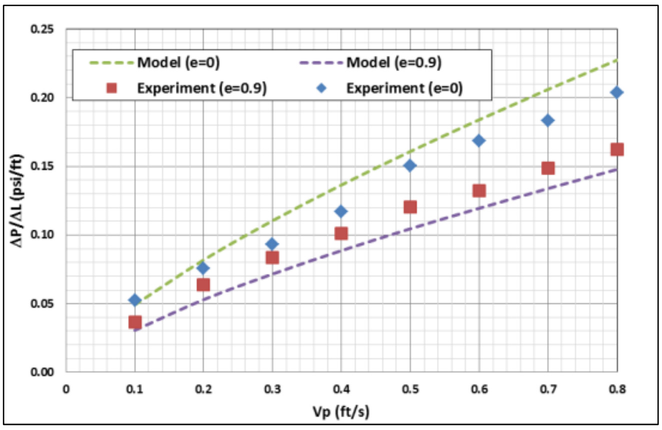

Fig. 5 The velocity and flow behavior index [43].

Surge pressure due to the inertia of the mud is due to the resistance of the drilling mud shaft to changes in motion as is evident from Newton's law of motion [44] as in equation (6):

$$F = ma = \rho va \tag{6}$$

Where:
ρ = fluid density.
v = fluid volume
a = acceleration, and the pressure of surge caused by force F is calculated from equation (7).

$$dp = \frac{F}{Da} = \frac{\rho va}{Da} = \rho adL \tag{7}$$

Where for open-ended pipes, fluid acceleration occurs both inside and outside the pipes, as in equation (8).

$$\frac{dpa}{dl} = \frac{0.00162\,\rho\,(D1 - D2)}{(B1 - B2)} \tag{8}$$

There is an approximation method for calculating the pressure of viscous swab, and its basic idea is to simplify to obtain approximate equations, and then simplify the equation and put it in terms of pipe velocity, properties of drilling fluid, well diameter and drilling pipe dimensions [45]. Using an efficient electronic calculator, and by performing calculations on more than 500 wells using a range of different diameters and clay properties, equations (5), (6), (7) and (8) were obtained [46].

Equation (9) is used for laminar flow for the closed ended pipes.

$$ps = B\,\mu_p\,Vp + \frac{\tau y}{0.3\,(D2 - D1)} \tag{9}$$

Equation (10) is used for turbulent flow the closed ended pipes.

$$Ps = A\,\mu\,p^{0.21Vp^{1.8}} \tag{10}$$

Equation (11) is used for laminar flow the open-ended pipes.

$$Ps = \beta\,\mu_p\,Vp + \left(\frac{\tau y}{0.3(D2 - D1)}\right) \tag{11}$$

Equation (12) is used for laminar flow the open-ended pipes.

$$Ps = \alpha\,A\,\mu_p\,P^{0.21\rho^{0.806Vp^{1.8}}} \tag{12}$$

Where:
Ps : swab pressure, psi.
A, B, α and $ß$: constant.
$D1$ and $D2$: pipes diameter, inch.
μ_p : fluid viscosity, cp.
τy : shear stress lb./100ft^2.
Vp : pipe velocity ft./sec.
ρ : fluid density, ppg.

Lapérouse, summarize the formulas and calculations for surge and swab pressures, as his method is based on the properties of drilling fluids and based on hydraulic calculations.

The calculation steps are summarized as follows equations (13) to (17) [47]:

1. The pressure around the drill pipe must be determine d2. The second step is to determine the pressure loss around the drilling collars. The total pressure loss must be determined by adding the numbers in step one and two. The last step is to determine the flow and pressure of the swab.

- **The first step:** determine pressure loss around drill pipe.

1. Determine.

$$n = 3.23 \log \left(\frac{\Theta 600}{\Theta 300} \right) \quad (13)$$

Where: n is the power law exponent. Θ600 is a value at 600 viscometer dial reading. Θ300 is a value at 300 viscometer dial reading.

2. Determine K using eq. (14).

$$K = \frac{\Theta 300}{511^n} \quad (14)$$

Where: K is the fluid consistency unit, Θ300 is a value at 300 viscometer dial reading. n is the power law exponent.

3. Determine fluid velocity around drill pipe using eq. (15).

For closed-ended pipe (plugged flow).

$$Vdp = 0.45 + \left(\frac{Dp^2}{Dh^2 - Dp^2} \right) \times Vp \quad (15)$$

For open-ended pipe using eq. (16).

$$Vdp = \left(0.45 + \frac{Dp^2 - Di^2}{Dh^2 - Dp^2 + Di^2} \right) \times Vp \quad (16)$$

Where: Vdp is the fluid velocity around drill pipe in ft/min. Vp is pipe movement velocity in ft/min. Dp is drill pipe diameter in inch. Dh is hole diameter in inch. Di is inner diameter of drill pipe in inch.

4. Maximum pipe velocity using eq. (17).

$$Vm = Vdp \times 1.5 \quad (17)$$

Where: Vdp is the fluid velocity around drill pipe in ft/min. Vm is maximum pipe velocity.

5. Pressure loss around drill pipe using eq. (18).

$$Pdp = \left(\left(2.4 \times \frac{Vm}{Dh} - Dp \right) \left(2n + \frac{1}{3n} \right) \right)^n \times \frac{KL}{300(Dh - Dp)} \quad (18)$$

- **The Second Step:** determine pressure loss around drill collar.

Also need to consider pressure loss around drill collar or BHA as well because they have different OD which sometimes creates significant surge/swab pressure.

1. Determine fluid velocity around drill collar using eq. (19).

For close-ended pipe (plugged flow).

$$Vdc = 0.45 + \left(\frac{Dc^2}{Dh^2 - Dc^2} \right) \times Vp \quad (19)$$

For open-ended pipe using eq. (20).

$$Vdc = \left(0.45 + \frac{Dc^2 - Di^2}{Dh^2 - Dc^2 + Di^2} \right) \times Vp \quad (20)$$

Where: Vdc is the fluid velocity around drill collar in ft/min. Dc is drill collar diameter in inch. Dh is hole diameter in inch. Dci is inner diameter of drill collar in inch.

- **The third step:** finding total pressure using eq. (21).

$$Total\ pressure\ loss = Pdp + Pdc \quad (21)$$

- **The final step:**

For surge pressure, finding the bottom hole pressure (Pbh) using eq. (22).

$$Pbh = Hydrostatic\ pressure + Total\ pressure\ loss \quad (22)$$

6.2. Computational algorithms and software tools

In this section, three main programs currently used in surge and swab pressures calculations will be discussed which are: Surge MOD, PVI's swab and Surge Hydraulics software and Commercial CFD software. Moving the pipe in the well is accompanied by the displacement of mud in the hole. This leads to differences in pressure. Accurate prediction of swab pressures and height is very important in wells where pressure must be kept within tight limits to ensure trouble-free drilling and completion operations. The Surge MOD is a fully hydraulic surge and survey model for drilling and completions. It analyzes complex downhole hydraulics when operating the casing or excursions for various pipe termination conditions and sub-tools of rotation. The Surge MOD not only predicts increments of stroke and swab pressure for a given operating speed, but also calculates optimal cruise speeds at various depths and the maximum allowable spin rate after the shell or liner is set. The result is a higher percentage of successful casing/liner runs and tripping runs; Especially in skinny holes and offshore deep wells. It is possible to use the Surge MOD software for predicting downhole pressure before running the casing or for calculating optimal running pipes speeds. PVI's swab and Surge Hydraulics software analyzes complex downhole hydraulics on casing operation or trip for different pipe termination conditions and sub-rotation tools. In addition, it allows engineers to avoid the loss of spin or kick resulting in higher success rates in liner/liner runs and other stumbling operations. Computational fluid dynamics (CFD) is the science of simulating problems related to flow using computer resources. Provides qualitative and quantitative fluid forecasts, mass transfer, heat transfer and related phenomena by solving mathematics equations. To address the fluid problem, first, it is necessary to know the physical properties of fluid system. Next, the analysis continues with a mathematical model for the physicist problem (partial differential equations).

Commercial CFD software, ANSYS Fluent and ANSYS CFX are used simulation of flow in the loop while reverberating on the inner tube, which is seen during well construction begins. Fluent uses a limited cell-centric size. The solution, where flow variables are stored at the center of the grid elements. The input parameters that are used for flow simulation in CFD software are well geometry, temperature, mesh number and slurry properties [47].

6.3. Comparative analysis of prediction models

Sometimes differential equations are used that describe the flow, whether (laminar or turbulent), and as was explained in the previous section, as in equations 1-8 to calculate surge and swab pressures. These equations are used to predict the movement of the pipes inside the drilling mud and vice versa, depending on the speed of the fluid inside the tube, the velocity of the tube movement, the inner diameter of the tube, and the viscosity of the fluid with the fixation of other factors. Pressures can be calculated through hydraulic calculations and specify a system, whether it is Bingham or Power, and here lies the difference between the two differential and hydraulic methods in entering the pump efficiency and pressure loss from within the calculation, and is certified in PVI's Swab and Surge Hydraulics program. As for the CFD analyzes, they depend entirely on the effect of the fluid on the calculations, and did not take into account the type of pump or the depths, but rather took into account the pressure required to break the gelatinous texture of the mud and accelerate or slow the fluids. As for Surge MOD software is comprehensive for all the above equations and programs. It is an integrated program that includes several options (fluid, depth, temperature, hydraulic, prediction and calculation, pipe [48], as shown in the Fig. 6.

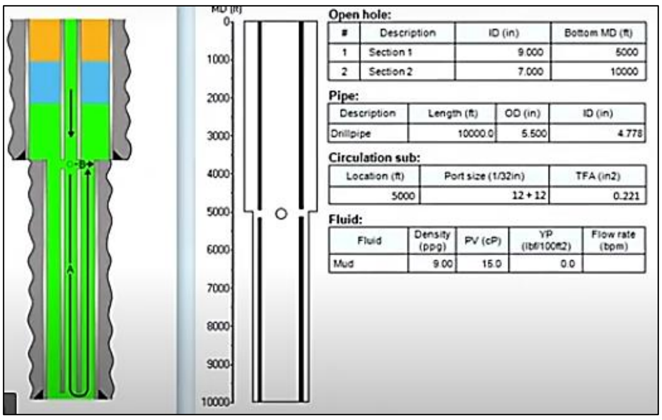

Fig. 6 The Surge MOD software, fully hydraulic surge and survey model [48].

7. Case studies and industry applications

7.1. Real-world case studies highlighting swab surge pressure challenges

Below is a case study in southern of Iraq, specifically the Tyarat and the Hartha layers. And since the formation of the Tayarat at 1417 m contains sulfur water with relatively high pressures greater than 0.465 psi/ft. The Tayarat are usually before the formation of Al-Hartha, which is a record, where when designing the drilling fluid for the second hole in which the two formations are located, the hydrostatic pressure must be taken into account mud density greater than 1.07 gm/cc. The pipes were withdrawn due to the replacement of the excavator, as the speed should be 4 ft/sec, but the driller exceeded this speed (increased it to 7 ft/sec), which led to the occurrence of swab pressure. The indication of this was the exit of sulfuric water with the return from the drilling fluid on trip tank, and then the sounding of warning sirens as a result of the liberation of hydrogen sulfide gas. As for the Al-Harth layer at 1758 m, the problem lies in the fact that the pipe was withdrawn to add drilling equipment, and the pipe was also lowered. The driller exceeded the speed set for descent according to the drilling program (from 3 ft/sec to 6 ft/sec) in order to reduce the time, which led to an increase in the hydrostatic pressure on the Al-Harth layer greater than the fracture pressure, and this in turn led to cracking of the layer and the occurrence of mud losses, and the indication of this is the absence of mud returns on the surface.

7.2. Lessons learned from industry applications

There must be sufficient knowledge of the excavated area and obtain basic information regarding the excavated layers of wells that have been excavated to reach the desired goal without entering into the problems of surge and swab pressures, including:

1. Geological information, including geological periods, starting from the surface to the depth (the estimated depth and upper limits of the formation and taking core samples). All of this information is important when pulling and lowering the pipes because some fragile layers require a specific speed for pulling and lowering and a specific type of drilling mud.
2. Information about the drilling fluids and the mud program, taking into consideration (the gradient of fracturing pressure of the rock formation, the pore pressure, and the possibility of well reflux), as the mud density has an important role, especially when calculating the speed of the pipes' descent and output, inversely proportional.
3. Drilling rig information. This section is concerned with the ability of the drilling rig to carry out all the operations that helped in drilling the well. One of the most important parts is the lifting device, which is the active part in the operations of the pipe journey, lifting and lowering.

8. Research challenges and future directions

8.1. Current research gaps and limitations

There should be studies related to reducing surge and swab pressures because, as indicated, the aforementioned pressures have a relationship with the journey time, which is directly related to the cost of drilling. As most of the studies directed towards the factors affecting the two pressures (surge and swab) without working to reduce it. Also, research is devoid of the effect of bottom hole drilling equipment assembly on the two pressures.

8.2. Emerging trends and technologies and future directions for swab surge pressure investigation

Artificial intelligence (*AI*) and automation are among the most technological trends that will continue to transform industries in 2023. Artificial intelligence will enable machines to smooth out errors, aggregate more than one factor, and make decisions and optimize factors. Where artificial intelligence can be used to identify factors that affect surge and swab pressures and check the degree of its impact. Fig. 7 shows statistics for six wells in field *x*. It turns out that the most common problems that cause drilling to stop are due to surge and swab pressures.

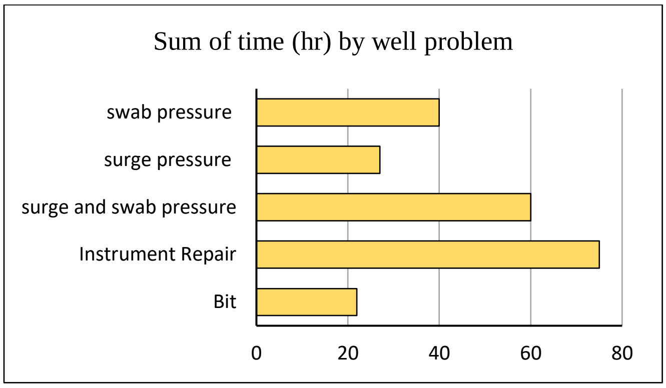

Fig. 7 Nonproductive time through drilling operations.

9. Conclusions

1. Key findings and insights from the review

Aspects that touch swab and surge pressures should be precisely designated with the intention kicks or blowouts control in addition preventing loss of circulation. This review and through studied about 48 references reached to that there are many factors effect swab and surge pressure. Managing the values of running in and out velocity of pipe through tripping is an influences factor to avoid swab and surge pressures. Flow behavior index n becomes smaller than 0.5 rapid rises in the pressure change happens. Declining power law constant K provides a growing in the pressure change. Recently, many new techniques have been used to reduce the side effect of swab and surge pressures for example using mathematical models to predict the surge and swab pressures, or using the Surge MOD software to give comprehensive calculations. It is promising to apply the conformal mapping on the eccentric annulus for mapping it to the concentric. Finally, it can be say that the surge and swab pressure investigation has a great significance to avoid problem caused by unsteady operation in management of pressure drilling (MPD) process. If the flow behavior index n be smaller than 0.5 a fast increase in pressure alteration occurs. The pressure alteration develops when the tripping speed is controlled between 0.33 m/s to 1 m/s.

2. Summary of recommendations for practitioners and researchers

The bellow ideas are recommended for the future works:

Further work needs to be done to incorporate impact deflection and piping rotation when increasing and swab pressure of the capacity law fluids. Experimental work with power law fluids is very limited in the literature, more experiments should be done with different fluids and geometries. Also, mathematical models lack the introduction of the effect of lithology for formations and formation temperatures. It is also possible to introduce the drill ability factor, Young's coefficient, and Poisson's ratio, as they are all related to formations.

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