SPE/IADC-221430-MS

Handling Gas-In-Riser – Part II: Numerical Simulation of Riser Equilibrium Point (REP), Riser-Gas Tolerance (RGT) and Riser Unloading, and Validation of the 2023 IADC Deepwater RGH Guidelines Calculation Worksheet

P. Cavalcanti de Sousa, Blade Energy Partners, Houston, Texas, USA; O. Gabaldon, Blade Energy Partners, Frisco, Texas, USA; O. Kaldirim, Pruitt Tool and Supply Co., Fort Smith, Arkansas, USA; P. Sonnemann, SafeKick Americas LLC, Katy, Texas, USA

This paper was prepared for presentation at the SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition held in Rio de Janeiro, Brazil, USA, 17 – 18 September, 2024.

Abstract

Several tools can simulate gas-liquid flow under typical operational conditions. However, the rapid expansion of gas in the riser (GIR) as it approaches the surface represents a challenge for many of these tools, as flow conditions fall outside assumptions used in developing their numerical models. Tools able to simulate the full transient behavior of GIR require expert setup and extended run-times. This work uses these tools to run simulations to estimate REP, RGT and riser unloading.

The simulation work shows that RGT is generally higher than what is perceived by the industry. This means risers can safely handle larger volumes of gas without exceeding their operational ratings, assuming the influx is circulated using the Fixed Choke, Constant Outflow (FCCO) method. The results also show that the riser equilibrium in WBM happens deeper in relation to SBM, all else remaining the same, and that riser unloading is more intense in WBM, with peak liquid and gas outflows surpassing those of SBM manyfold. The results are also used to evaluate the reliability and intended conservative nature of the RGT Worksheet.

This work demonstrates through simulation that GIR can be safely handled with existing surface equipment in many rigs. This represents a significant reduction in NPT and minimizes risks. The authors also demonstrate that calculations performed using the simplified methods considered in the RGT Worksheet can give conservative safeguards to offshore operations.

Introduction

The management of gas-in-riser (GIR) events in deepwater drilling is a critical challenge due to the rapid expansion of gas as it ascends, leading to complex flow conditions that many existing simulation tools struggle to predict accurately. "Handling Gas-In-Riser – Part I: Fundamental Concepts and Calculations Underlying 2023 IADC Riser Gas Guidelines" (P. Sonnemann 2024) laid the groundwork by defining key terms and concepts and addressing the calculation methodologies fundamental to the 2023 IADC Deepwater

Riser Gas Handling (RGH) Guidelines and the associated Riser Gas Tolerance (RGT) Worksheet. This foundational work clarifies the principles of riser equilibrium and unloading.

Building on these foundational concepts, this work explores further the real-life implications of these principles through advanced numerical simulations. These simulations aim to estimate the riser equilibrium point (REP), assess the riser-gas tolerance (RGT), and analyze the unloading behavior of risers under various operational conditions. The use of sophisticated models capable of capturing the full transient behavior of GIR, despite requiring expert setup and extended run-times, provides critical insights into these phenomena.

The results of these simulations reveal that the industry may have underestimated the RGT, indicating that risers can safely manage larger volumes of gas without exceeding their operational ratings when the influx is handled using the Fixed Choke, Constant Outflow (FCCO) method (IADC 2023), which is explained and demonstrated in the works of (O. Gabaldon 2022) and (T. A. M. R. Kunju 2024). Additionally, the research identifies significant differences in the behavior of water-based mud (WBM) and synthetic-based mud (SBM), with WBM exhibiting deeper equilibrium points and more intense unloading.

Moreover, this paper evaluates the reliability and intended conservative nature of the RGT Worksheet and the 2023 IADC Deepwater RGH Guidelines. The findings demonstrate that GIR can often be managed safely with existing surface equipment on many rigs, thus enhancing operational safety and reducing non-productive time, while minimizing chances of overboard discharge events.

This paper provides the industry with validated tools and methodologies for better managing GIR events, thereby promoting safer and more efficient deepwater drilling operations. By building on the fundamental concepts introduced in the first part of this series, it aims to ensure a consistent and practical approach to riser gas handling in the field.

IADC Deepwater RGH Guidelines Calculation Worksheet Comparative Study

The IADC Deepwater RGH Guidelines Calculation Worksheet, or the Riser-Gas Tolerance (RGT) Worksheet, or simply Worksheet, is a product of the work developed by the members of the RGH subcommittee of IADC's UBO and MPD committee. The objective of the RGT Worksheet is to simplify what are otherwise considered convoluted calculations, which would normally require the use of advanced tools capable of simulating transient multiphase flow. Therefore, the RGT Worksheet was designed not only to be user-friendly, but also to provide conservative results. To demonstrate the robustness of the RGT Worksheet, we conducted a series of simulations using Drillbench 2022.2.2, which differently from its previous versions, runs on OLGA, a state-of-the-art multiphase simulator commonly used as a benchmark in the Oil and Gas industry.

The intent of this paper is to demonstrate the flexibility of handing gas inside of the riser through a comparative study between numerical simulations and the RGT Worksheet. The main assumption used in all simulations and the RGT Worksheet is that the RGH procedures only take place after the Subsurface BOP (SSBOP) is closed and the well is secured and isolated from the riser. All other relevant assumptions and basic parameters representing the issue at hand are summarized in Table 1.

The influx size varies, but we assume it arrives at the bottom of the riser as a single bubble that is neither dispersed nor in solution. Once the gas is at the bottom of the riser, it must be removed by one of the following methods:

- Shut-in at start: immediately after the bubble is completely above the SSBOP, the riser is shut-in at bottom and top, and the bubble is allowed to migrate without pressure relief.
- FCCO: riser-gas is circulated out using the FCCO method described earlier.
- FCCO and shut-in (FCCO&SI): the gas is circulated up the riser using the FCCO method until the pump rate is reduced to zero. At this point, the riser is shut-in and the gas migrates with no pressure relief.

- Riser gas tolerance: the maximum surface pressure if riser is shut-in when the top of the gas reaches REP depth.

Table 1—Basic parameters used in all analysis.

Fixed Parameter	Values	Unit
Riser Inner Diameter	19.25	in.
Drillpipe Outer Diameter	6.625	in.-
Atmospheric Pressure	14.7	psia
Surrounding Temperature	50	°F
Mud Plastic Viscosity (PV)	19	cP
Mud Yield Point	27	lbf / 100 ft^2
Influx Gas	Methane	-

With that in mind, we designed an extensive simulation matrix which includes high and low scenarios of important drilling parameters typically encountered in offshore campaigns. Table 2 shows the different parameters used in this study and their respective values.

Table 2—Parameters used in the sensitivity analysis of the IADC Deepwater RGH Guidelines Calculation Worksheet.

Sensitivity Parameter	Values	Unit
Riser Length	3,000 and 8,000	ft
Mud Type	WBM and SBM	-
Mud Density	9.0 and 12.0	ppg
Initial Gas Bubble Volume (at the bottom of the riser)	50 and 200	bbl
Pump Rate	0, 100 and 400	gpm
Gas Circulation Method	Riser Unloading (no pumps), Shut-In at Start, FCCO, and FCCO&SI	-

With the simulation parameters given in Tables 1 and 2, the only remaining undefined variable is the gas migration velocity. Gas migration rates are difficult to predict since the gas migration velocity is impacted by multiple factors, including the gas bubble dispersion in the annulus. Large gas bubbles tend to migrate faster, while the same volume of gas, dispersed in small bubbles (e.g., bubble swarms) migrate much slower. Such slow-migrating bubbles tend to coalesce into larger bubbles, increasing the migration velocity and flow regime properties. On the other hand, larger, fast-migrating bubbles tend to create more turbulence, which may lead to the breaking of said bubble in smaller, slow-moving ones. This is a very dynamic, ever-changing process which will also be impacted by acceleration as the gas expansion while it travels up the riser. This complex process has proven virtually impossible to describe mechanistically, resulting in a variety of empirical models, all with significant limitations to accommodate variable conditions in a wide range of operational conditions.

The RGT Worksheet calculates two parameters which are significantly impacted by the user's assumption of gas migration velocity: (a) the moment when the boost pumps are required to be stopped during the implementation of FCCO method (i.e., when the flow rate out of the riser due to gas expansion equals the boost rate), and (b) the maximum surface pressure if the riser is shut in at the time when the boost pumps are stopped during the implementation of FCCO method. Since these calculations rely on the user input of gas migration velocity, the results can be largely under- or overestimated, depending on the velocity assumption.

Therefore, the users of the RGT Worksheet should exercise caution, and avoid using these parameters to prepare operational procedures or riser gas handling plans for actual operations. The FCCO method is simple, but its implementation is highly dependent on the rig's equipment, geometry, operational layout, etc. The FCCO will account for the actual migration rates inherently, as its execution should be based on real-time observations rather than a predefined schedule.

The Worksheet results presented in this work are based on four different bubble migration velocities: (i) bubble velocity from the shut-in formula, (ii) Taylor bubble velocity, (iii) the averaged bubble migration velocity from the simulation, and (iv) a varying velocity based on the simulation results. The varying velocity option was obtained by modifying the original RGT Worksheet which would not allow for that as an input.

The shut-in formula is an empirical correlation derived from several field observations and it is given by (Lapeyrouse 2002) as

$$v_{SI} = 12 \quad \exp\left(-0.37 \times MW\right),$$

where MW is the mud weight (liquid density) in ppg, and v_{SI} is the bubble migration velocity calculated in ft/sec.

A Taylor bubble is a bullet-shaped bubble that fills almost the entire cross-sectional area of a pipe while it migrates upwards in a liquid, and it has been studied extensively for several decades. In this study, we use the correlation presented in the work of (F. Viana 2003) which allows for the calculation of the Taylor bubble velocity based on liquid and gas densities, pipe geometry, and surface tension of the liquid.

The use of the shut-in formula and the Taylor bubble correlation provides us with the bubble migration velocities shown in Table 3. It is interesting to observe that, given the dimensions of the riser, the Taylor bubble correlation results in the same velocity for both mud weights considered.

Table 3—Estimated bubble migration velocities.

Mud Weight (ppg)	Bubble Velocity (ft/hr)	
	Shut-In Formula	Taylor Bubble Correlation
9.0	1,546	7,122
12.0	510	

It is important to add that, as it will be shown in the following paragraphs, the simulated bubble migration velocities were, in general, higher than initially estimated by the values in Table 3. Not only that, but the bubbles also accelerated considerably. While this is to be expected, the bubble migration velocities obtained from the simulations reached values greater than 5,000 ft/hr in all cases with WBM, which, in the authors' opinion is excessive. Field observations and lab-scale experiments ((O. Kaldirim 2018), (M. A. M. R. Kunju 2023), (Y. Moganaradjou 2024)) show that the bubble migration velocities in WBM are lower than 1,500 ft/hr. In fact, it is considered that Taylor bubble velocity is the upper boundary of gas migration, and this is why, in this work, this criterion was initially chosen as a worst-case scenario. Nonetheless, given these unforeseen ranges of bubble migration velocities, we added two new criteria to be analyzed with the Worksheet. First, we used the average velocity obtained from simulation, and second, we modified the Worksheet such that it would be able to take the acceleration of the migration process into account. The acceleration is also determined from the simulation results.

With that, all the simulation parameters and Worksheet inputs are set, and results can be determined. Next, we will discuss each one of the comparison points drawn earlier in this Section and evaluate how the Worksheet performs relative to the numerical simulation.

Simulated FCCO vs. Worksheet Output

These simulations were run to demonstrate the difference in depth at which point the booster pump rate goes to 0 gpm to maintain 200 psi surface pressure with the choke maintained at the initial position as per the FCCO method. The simulations were run with 12 ppg and 9 ppg mud weights using water-based mud (WBM), for 3,000-ft and 8,000-ft risers. As per the FCCO method, the pump rate was staged down to maintain 200 psi SBP until the pumps were turned off. The simulated FCCO and Worksheet results were plotted to provide the comparison of the results.

Fig. 1 shows the simulation results for a 50 bbl gas influx at the bottom of the 3,000 ft riser, with 12 ppg mud weight, with the simulated FCCO method in red and the worksheet result with the Taylor bubble velocity (7,122 ft/hr) in green. The blue line in the graph represents the migration velocity of 510 ft/hr, calculated as per the shut-in formula. The dotted and solid black lines are from the worksheet representing the 705 ft/hr averaged velocity and varying bubble velocity. The Taylor bubble simulation demonstrates the most extreme case with the pump rate going to 0 when the gas bubble reaches 700 ft below RT. The varying velocity-based worksheet results demonstrated the closest match to the simulated FCCO results. The results from the worksheet with shut-in migration velocity and the averaged velocity demonstrate significant difference from the simulated FCCO results.

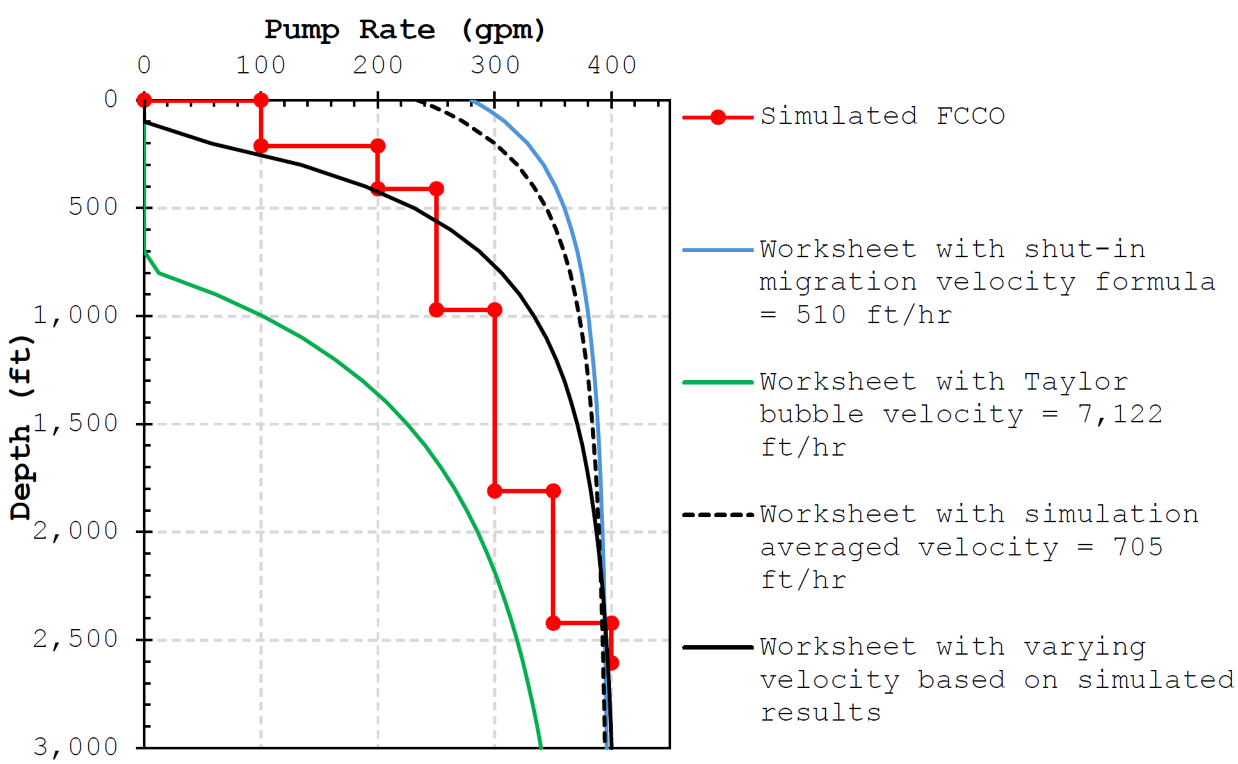

Figure 1—Worksheet results for a 50 bbl influx at the bottom of a 3,000 ft riser with 12 ppg WBM, riser booster at 400 gpm at the start of the circulation, and different gas migration velocities.

The difference between the different migration velocity results become clearer with large gas influx volumes in a shorter riser, as demonstrated in Fig. 2 with a 200 bbl gas influx inside a 3,000-ft riser. The starting pump rate used for the simulated FCCO method and the worksheet results was 100 gpm. The simulated FCCO result demonstrates that the pump rate is staged down to 0 gpm at 1,700 ft from RT, while the worksheet result with varying velocity requires pump rate to be staged down to 0 gpm at 2,600 ft from RT. The worksheet result using the shut-in migration velocity allows for pump rate to be gradually staged down to 0 gpm as the top of the bubble arrives at 700 ft. The Taylor bubble velocity and the averaged velocity results don't allow for pumping due to the higher than 200 psi surface pressure.

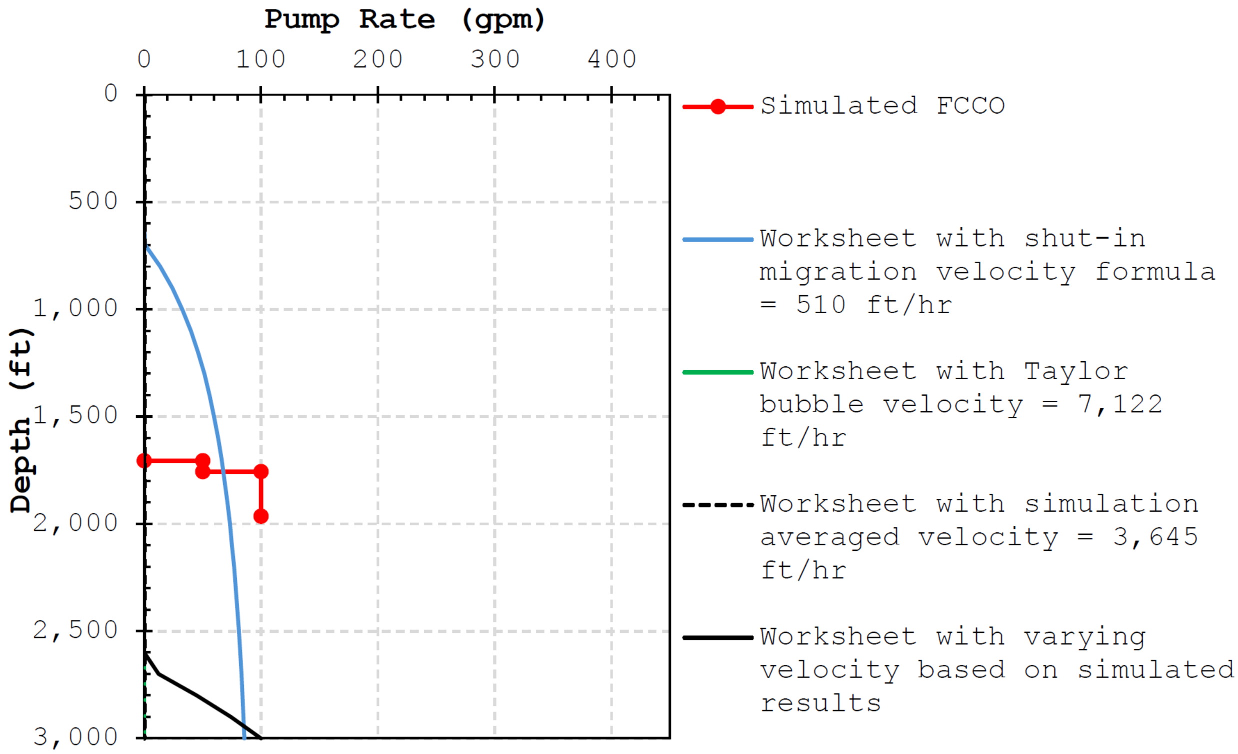

Figure 2—Worksheet results for a 200 bbl influx at the bottom of a 3,000 ft riser with 12 ppg WBM, riser booster at 100 gpm at the start of the circulation, and different gas migration velocities.

Fig. 3 shows the 50 bbl gas influx on bottom in an 8,000 ft riser. The Simulated FCCO results and the Worksheet results with both averaged velocity of 10,007 ft/hr and varying velocity migration rate demonstrate close results in terms of when the pump rate is staged down to 0 gpm. The simulated FCCO results in 0 gpm pump rate at 2,700 ft from RT, while the averaged velocity result calls for 0 gpm at 2,000 ft from RT, and 3,300 ft from RT when a varying velocity is implemented in the Worksheet. The Worksheet results with the Taylor bubble velocity in this case underestimates the point at which the pump rate goes to zero when compared to the simulated FCCO result with 0 gpm pump rate at 2,000 ft from RT. When the shut-in migration velocity of 510 ft/hr is used in the Worksheet, the result is greatly underestimated with maintaining 100 gpm pump rate with gas at surface.

The 200 bbl gas influx case was run also in 8,000 ft of riser with a 9 ppg WBM and the results were plotted in Fig. 4. In this case the initial pump rate was 100 gpm. As seen in Fig. 4, the simulated FCCO results in 0 gpm at 5,900 ft, while the varying velocity results in 0 gpm pump rate at 6,900 ft from RT. The averaged velocity of 3,445 ft/hr results in 0 gpm at 5,300 ft. The result for the worksheet with Taylor bubble velocity required 0 gpm pump rate as soon as the gas influx was placed in the bottom of the riser. The shut-in migration velocity on the worksheet called for the pumps to be staged down to 0 gpm at 3,200 ft from RT.

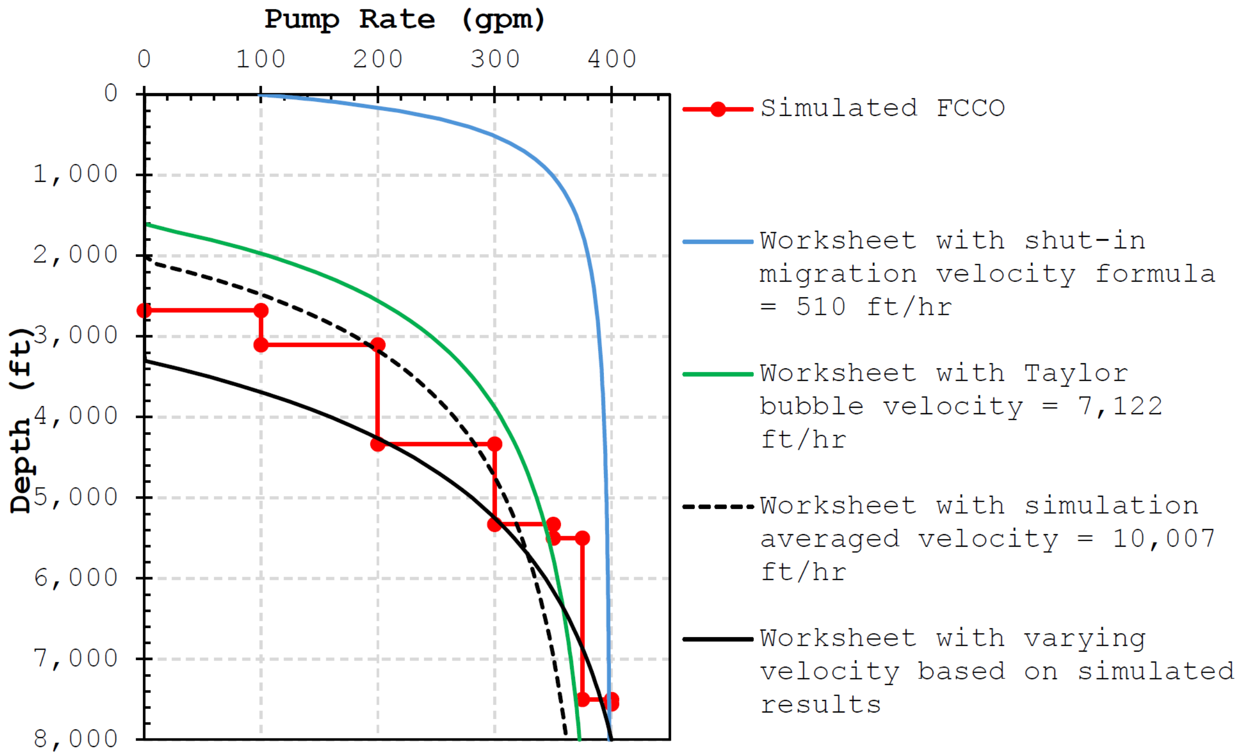

Figure 3—Worksheet results for a 50 bbl influx at the bottom of an 8,000 ft riser with 12 ppg WBM, riser booster at 400 gpm at the start of the circulation, and different gas migration velocities.

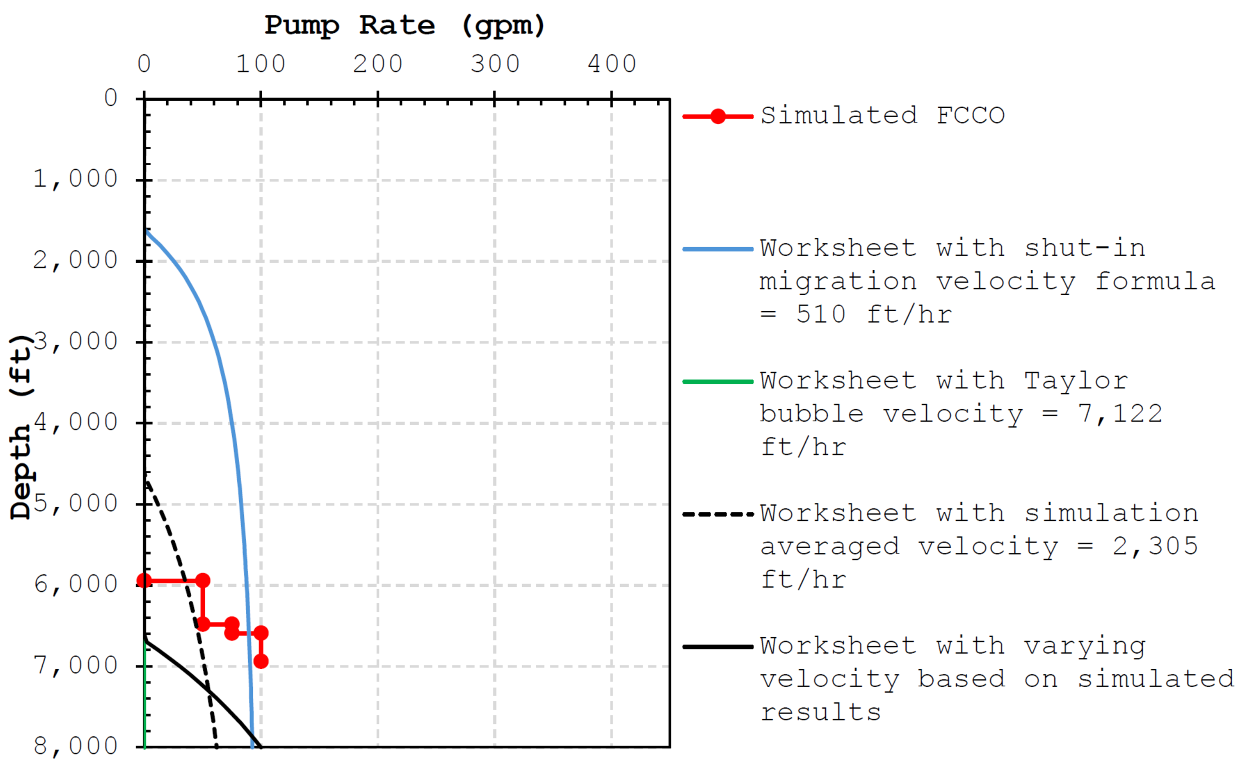

Figure 4—Worksheet results for a 200 bbl influx at the bottom of an 8,000 ft riser with 12 ppg WBM, riser booster at 100 gpm at the start of the circulation, and different gas migration velocities.

It is reasonable to say that, based on the data presented in Figs. 1 through 4, the RGT Worksheet can result in reliable values if proper assumptions are taken. The acceleration of the bubble and consequent higher-than-expected migration velocities go beyond the initial boundaries set for the RGT Worksheet. Nonetheless, a simple modification allowing to consider such acceleration has resulted in consistently conservative results, which confirms the robustness of the method and the Worksheet itself.

Simulated FCCO&SI vs. Worksheet Output

The second simulation scenario is similar to the one just analyzed; however, now the FCCO method is followed by a riser shut-in once the pumps are brought to zero flow rate. Under these circumstances, the bubble is allowed to migrate to the top of the riser without pressure release either from the top or from the bottom, and we must determine what the end pressure on top of the riser will be.

The maximum surface pressure observed for each simulation was tracked and displayed in Fig. 5. The greatest maximum pressures are observed when the varying bubble velocity method is applied into the worksheet. The worst-case scenario being the 8,000 ft riser, 200 bbl gas influx on bottom with 12 ppg WBM, with the starting booster pump rate of 100 gpm yielded a maximum surface pressure of 4,800 psi. In all simulation and Worksheet cases, the lower mud weight resulted in lower maximum surface pressure. Similarly, the 400-gpm starting rate yielded a lower maximum surface pressure than the 100-gpm starting rate. In all cases, the synthetic base mud (SBM) demonstrates a significantly lower maximum surface pressure. Even though the varying velocity method results in the closest approximation to the pumps-off depth, as demonstrated in the previous Section, the use of the same method results in a consistently overestimation of the final surface pressure after gas migration, when compared to simulated results.

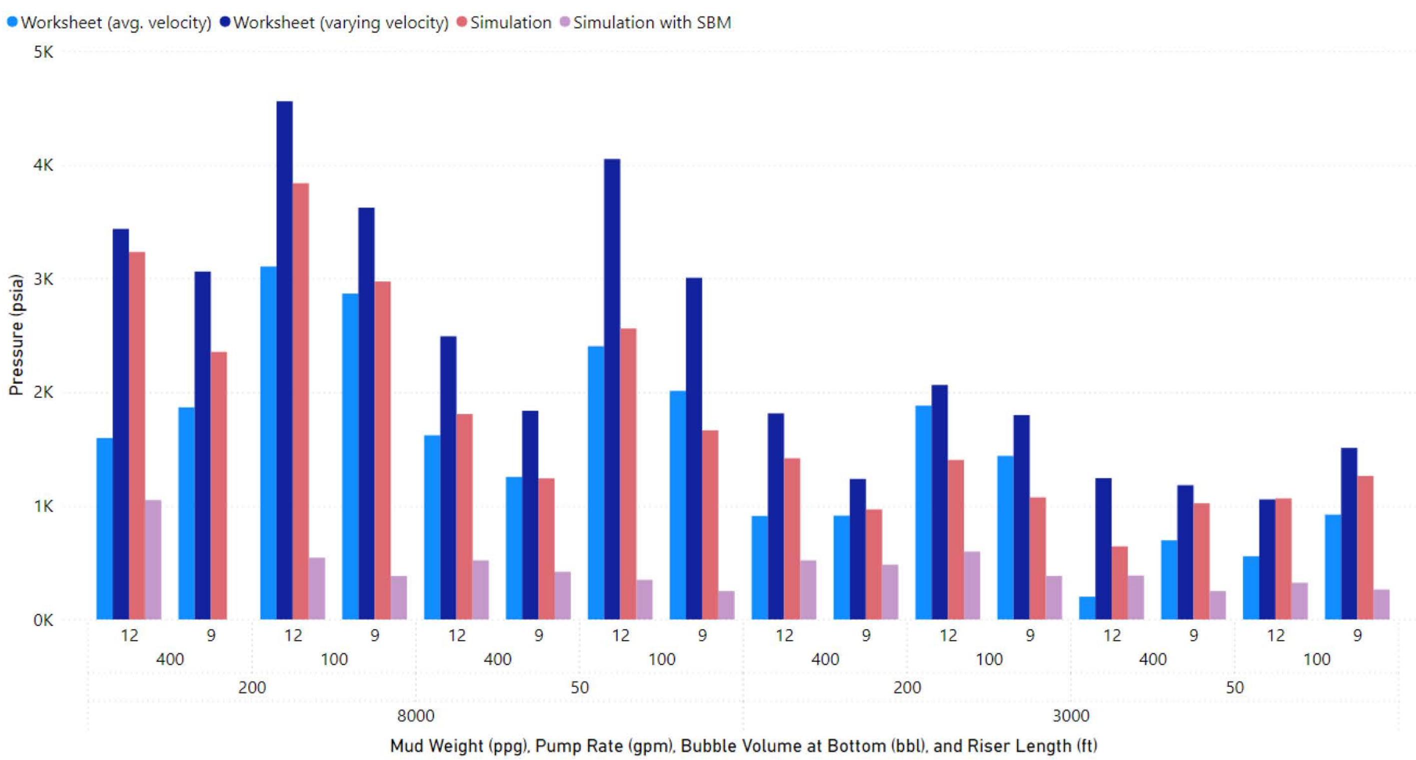

Figure 5—Pressure at surface after gas migrates to top of the riser following shut-in after pump rate is reduced to zero during FCCO.

Again, like in the previous scenario, the Worksheet results are conservative in relation to the simulation values when the acceleration of the bubble is considered. In the case of the averaged, but constant, velocity, the results vary significantly and do not represent a reliable predictor for the simulation results. Therefore, we must reinforce that the Worksheet can be a reliable tool as long as representative values are used.

Simulated Shut-In at Start vs. Worksheet Output

Another shut-in scenario studied here concerns the case where the FCCO method is not executed, but rather the riser is shut-in as early as possible, that is, when the influx is just above the SSBOP. In this study, the migration velocity is not a concern, but the compressibility of the mud is taken into consideration.

Fig. 6 shows that the Worksheet results in conservative estimates, with the final surface pressure always being consistently higher than the simulated result. The simulations also show that the surface pressure when SBM is used is significantly lower than in the cases with WBM. This is to be expected and it is largely caused by gas solubility in the mud.

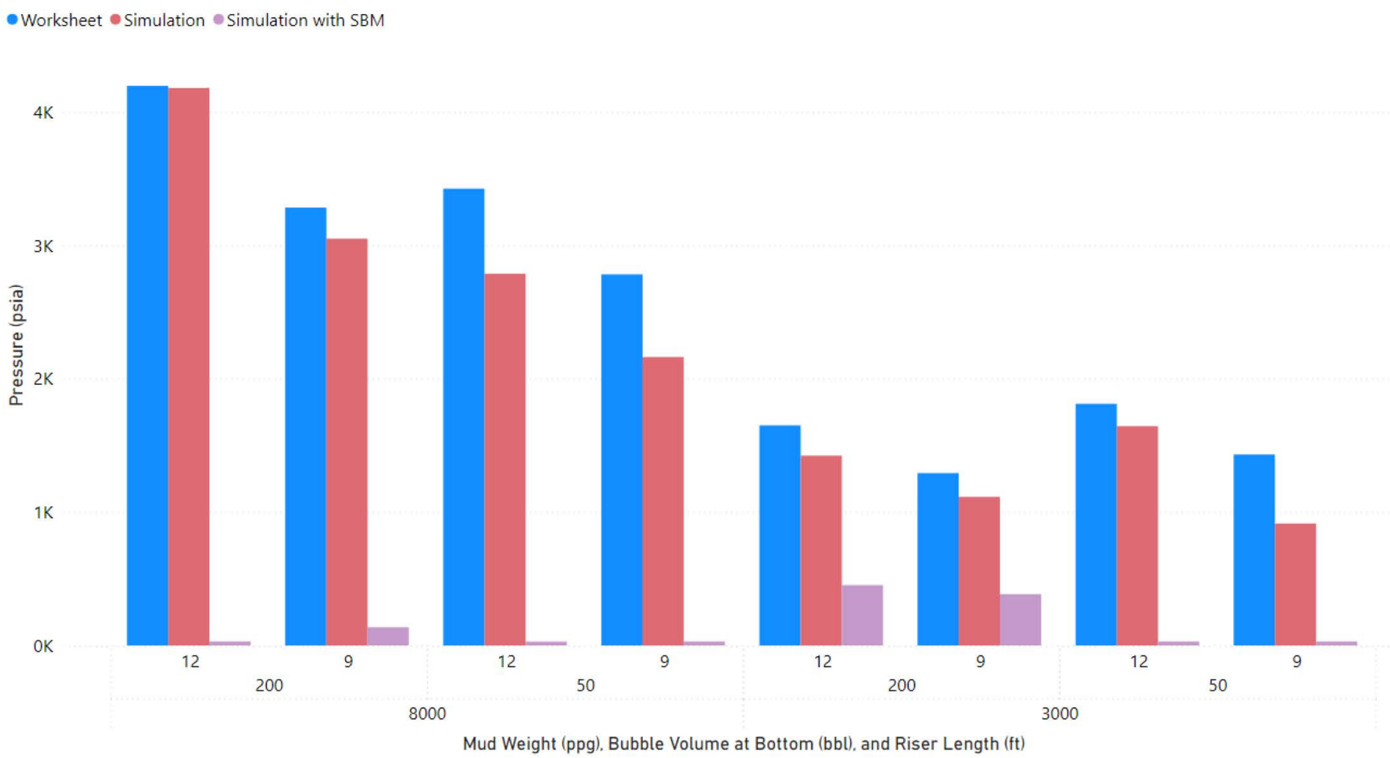

Figure 6—Pressure at top of the riser after gas migration following shut-in when gas is at bottom of riser.

Riser-Gas Tolerance Calculation (Worksheet) vs. Simulation

The Worksheet allows its users to understand what happens during gas-in-riser events and provides a high-level tool to understand and devise actions need to properly handle gas at surface. Then, we carried out extensive simulation work to demonstrate the Worksheet is indeed a conservative resource, given the inputs the user enters are representative of the scenario being analyzed.

In that regard, the first part of this work (P. Sonnemann 2024) defined Riser Gas Tolerance as the maximum surface pressure allowed after the gas migrates to surface if shut-in at REP depth and provided a graphical means to determine what the RGT is for a given system. Here, we will elaborate on that concept and derive an equation for direct calculation of RGT.

From the definition given above, the maximum allowed surface pressure (MASP) must be equal to the pressure on top of the gas bubble at the REP depth. Thus,

$$MASP = P_{REP} = \sqrt{\frac{\rho_L g V_0 P_0}{C}} = \sqrt{\frac{\rho_L g V_0}{C}\left(P_{S0} + \rho_L g H_R - \rho_L g \frac{V_0}{C}\right)}, \quad (1)$$

where g is the acceleration due to gravity, ρ_L is the density of the liquid (mud weight), C is the riser capacity, V_0 is the initial volume of the bubble at the bottom of the riser, P_{S0} is the initial surface pressure, including atmospheric, and H_R is the total length of the riser.

By squaring both sides of Eq. 1 and some simple algebraic manipulation we can rewrite it as

$$\left(\frac{\rho_L g}{C}\right)^2 V_0^2 - \left(\frac{\rho_L g}{C} P_{S0} + \frac{(\rho_L g)^2}{C} H_R\right) V_0 + MASP^2 = 0.$$

Now, we redefine V_0 as the RGT itself to obtain

$$RGT = \frac{\beta \pm \sqrt{\beta^2 - 4 \quad \alpha^2 \quad MASP^2}}{2\alpha^2}, \qquad (2)$$

with

$$\alpha = \frac{\rho_L g}{C},$$

And

$$\beta = \alpha P_{S0} + \alpha \quad \rho_L g \quad H_R.$$

From Eq. 2, we can calculate the Riser-Gas Tolerance for the scenarios evaluated in this study, which are shown in Table 4. We set the MASP for the 8,000-ft riser at 1,250 psig. Notice, however, that we used MASP = 500 psig for the shorter 3,000-ft riser since the surface pressure calculated for any influx volume would always be less than 1,250 psig in that scenario.

Table 4—Calculated and Simulated riser-gas tolerance for different scenarios.

MASP (psig)	Riser Length (ft)	Mud Weight (ppg)	REP Depth (ft)	RGT (bbl)	Simulation Surface Pressure (psig)	Relative Difference Simulation to MASP
500	3,000	9.0	1,050	148.7	510	+2.1%
500	3,000	12.0	794	77.5	482	-3.6%
1,250	8,000	9.0	2,557	325.5	1,248	-0.1%
1,250	8,000	12.0	1,958	172.3	1,292	+3.4%

Table 4 shows that the RGT Worksheet results agree with the surface pressure obtained from simulation, with differences within 5% from each other. This result confirms not only the robustness of the RGT Worksheet, but also the validity of the REP concept.

Finally, limited simulations were performed to compare experimental results from (T. A. M. R. Kunju 2024). An exact side-by-side comparison was not possible as the simulation tool presented some limited capabilities for using Nitrogen as the influx gas, as used in the experiments. Also, the fluid system in the simulator was limited to conditions different than the fluids properties used in the experiment. Still considering these limitations, the preliminary results are encouraging, showing consistent behavior in the resulting parameters, when compared to those captured during the experiments. Further work in this area is ongoing, using a more advanced simulator.

Conclusions

The findings of this study underscore the effectiveness and reliability of the 2023 IADC Deepwater Riser Gas Handling (RGH) Guidelines and the associated Riser Gas Tolerance (RGT) Worksheet when appropriate assumptions are applied. The detailed numerical simulations presented in this paper provide significant insights into the behavior of gas-in-riser (GIR) events under various conditions, offering several key conclusions:

- The RGT Worksheet can yield reliable values if proper assumptions, including the acceleration of the gas bubble, are considered. The inherent conservatism of the Worksheet is maintained even when modifications are made to account for bubble acceleration, confirming the robustness of both the method and the Worksheet itself.
- The acceleration of the gas bubble calculated by the numerical simulation leads to higher-than-expected migration velocities, which extend beyond the initial boundaries set for the RGT Worksheet. Despite this, incorporating a modification to account for bubble acceleration has consistently produced conservative results, reinforcing the reliability of the Worksheet under varying conditions. A significant variance in results is observed when an averaged, constant velocity is used compared to the acceleration-inclusive approach. The results from using a constant velocity do not reliably predict the simulation outcomes.
- The RGT Worksheet consistently provides conservative estimates, with final surface pressures being higher than those obtained from simulations. This conservative nature is beneficial for operational safety, offering an additional margin of security in real-world applications.
- The simulations show that the surface pressure when using synthetic-based mud (SBM) is significantly lower than when using water-based mud (WBM). This difference is primarily attributed to the gas solubility in the mud, which is more pronounced in SBM, leading to lower surface pressures during GIR events.

Overall, the study shows that the conservative estimates provided by the RGT Worksheet, especially when considering bubble acceleration, validates its use as an effective tool for understanding the concepts involved in GIR events. Moreover, the results reinforce the safety and reliability of the 2023 IADC Deepwater RGH Guidelines and the FCCO method to manage GIR events. The insights gained from this study encourage the continued use and refinement of these tools, promoting safer and more efficient management of gas-in-riser scenarios in the industry.

References

F. Viana, R. Pardo, R. Yanez, J. L. Trallero, D. D. Joseph. 2003. "Universal correlation for the rise velocity of long gas bubbles in round pipes." *Journal of Fluid Mechanics* **494**: 379–398. doi:S0022112003006165.

IADC. 2023. Riser Gas Handling Guidelines (RG) – Stand-alone Chapter of the IADC Drilling Manual. IADC.

Lapeyrouse, N. J. 2002. Formulas and Calculations for Drilling, Production and Workover. Elsevier Science.

M. R. Kunju, M. A. Almeida. 2023. "Analysis of Riser Gas Pressure from Full-Scale Gas-in-Riser Experiments with Instrumentation." *SPE Drill & Compl* **38**: 170–186. doi: https://doi.org/10.2118/206389-PA.

M. R. Kunju, T. Adeyemi, J. Sharma, M. A. Almeida. 2024. "Fixed Choke Constant Outflow Circulation Method for Riser Gas Handling: Full-Scale Tests in Water- and Synthetic-Based Mud with Gauges and Distributed Fiber-Optic Sensors." *SPE Journal* **29** (01): 87–105. doi:doi.org/10.2118/217444-PA.

O. Gabaldon, R. A. Gonzalez, P. Cavalcanti de Sousa, Y. Chen. 2022. "Expanded IME with New Riser Gas Handling Operation Region." SPE/IADC Managed Pressure Drilling & Underbalanced Operations Conference & Exhibition. Kuala Lumpur, Malaysia.

O. Kaldirim, J. J. Schubert. 2018. "Experimental Study on Riser Gas Expansion and Unloading." SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition. New Orleans, USA. doi: https://doi.org/10.2118/190004-MS.

P. Sonnemann, M. L. Teixeira, G. Humphreys, S. Christman, P. Cavalcanti de Sousa. 2024. "Handling Gas-In-Riser – Part I: Fundamental Concepts and Calculations Underlying 2023 IADC Riser Gas Guidelines." SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition.

Y. Moganaradjou, G. A. Samdani, M. A. Almeida, M. K. Kunju, V. P. Gupta. 2024. "Field Scale Tests & Modeling to Forecast Gas Migration Rates for Pressurized Mud Cap Drilling (PMCD) Applications." IADC/SPE International Drilling Conference and Exhibition. Galveston, TX.