Sand Production Prediction Model: An integrated approach for production management of multi-phase field East coast of India.

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Keywords

Thick wall cylinder test; Onset of sanding; Water induced sanding; Sand production prediction model.

Summary

Sand production is one of the major techno-economical challenges in offshore clastic reservoirs to optimize production. The sanding in deep water reservoir can cause operational problems and safety hazard like well shut-in, erosion of surface facilities and adversely affect the field economics if proper completion and production planning are not done in such scenario. Sand production prediction model will act as a tool for deciding the type of completion and production strategy, which reduces the risk of sand production through the production life of the field. An integrated sand prediction model was being used to discuss the mechanism governing the sand production as well as accurate prediction of critical bottom hole pressure where sanding starts for producing wells within study area. The sand prediction model results have been used to optimize the completion strategy for upcoming wells as well as operating drawdown of producing wells.

The integrated approach incorporates laboratory measurements (thick wall cylinder test), rock mechanical properties of the reservoir (rock strength), reservoir stress state, and heterogeneity of rock along with production parameters. The magnitude of sand production risk was classified (onset/total failure) by calibration with the nature of sand prediction during thick wall cylinder test and field sand production results. The model suggests the high magnitude of sand production risk increases with depletion, whereas there is sharp drop in operating drawdown of high water producing wells, as the risk of sanding production increases due to drop in TWC strength.

Introduction

The study area **(Figure 1)** is a depleted oil, condensate & gas field in the Krishna –Godavari basin, East Coast of India and reservoir sands are Mesozoic in age. Reservoir is depleted by about 45-50% from its original state. The well 'A' was drilled and completed in the depleted stage of the field, during the initial phase of the ramp-up, sand production was observed which was used to calibrate the sand prediction model of the field. The calibrated sand prediction model was used to predict and identify the magnitude of sanding risk for producing wells.

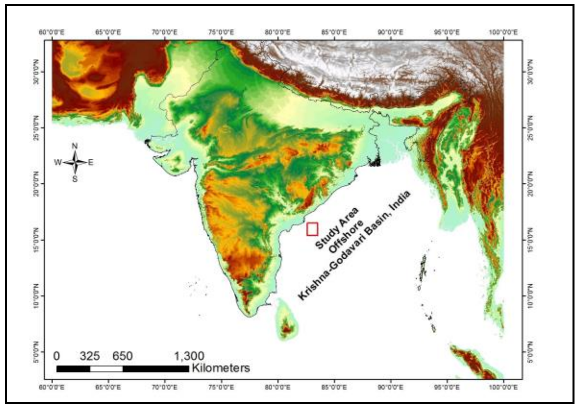

Figure 1 : Location map of the study area.

The sand failure mode can be further subdivided into different stages depending on the magnitude of sanding; (1) The onset of sand production: failure initiates the sand particles are not totally disaggregated, (2) Catastrophic Failure: highly shear failure and totally disaggregated and decemented, and (3) Catastrophic failure with Water production: No cement and adhesion & totally disaggregated. The mechanism resulting in the mechanical dis-aggregation of reservoir sand will control the volume of the produced sand (Vaziri et al., 2002).

In most of the cases, the sand production model is based on a single failure mode. In this scenario, it is challenging task to predict whether sand production can be managed or not without field experience, especially where the production facility has a tolerance limit for solid production. In this study, all three reservoir failure states; sand initialization, catastrophic failure and failure with high water production have been modelled to quantify the risk of sand production in the producing wells considering the current reservoir pressure production parameters. The main driver of this analysis has been to quantify the risk of sand production for producing wells and decide the completion strategy for upcoming wells (whether the wells at current depletion/future production can be completed without sand control). The potential advantage of no sand control is cheaper, low operational risk and better production. Another driver was to assess whether an increase in drawdown can boost the well performance without excessive sand production for the wells completed with standalone screens. Based on the calibrated sand prediction model, completion strategy of upcoming wells was revised from SAS (Stand Alone Screen) to OHGH (Open Hole Gravel Pack) and drawdown of the different wells was optimized to have maximum gas production without sand production.

Sand Production Prediction Model: Input Parameters

The main input parameters required for the assessment of sand production prediction are rock-strength data (TWC-Thick wall Cylinder and UCS-Uniaxial Compressive Strength), sub-surface stresses (vertical, maximum and minimum horizontal stress magnitude and azimuth of maximum horizontal stress), reservoir pressures and effect of pressure depletion.

Thick-Walled Cylinder Test (TWC):

In the sanding model, the collapse pressure of thick-wall cylinder test is used as the strength measure for unsupported boreholes/perforations. The advance thick-wall cylinder test (ATWC) is equipped with a weight balance at the bottom of the sample which provides the direct measurement of produced/failed sand and measures the weight of the same. Also, two strain gauges are attached at the inner wall of the cylindrical hole sample, which directly monitors the onset of sand production during the test. In other words, ATWC test results can be used to estimate the pressure of the onset of sand production as well as pressure at the catastrophic failure **(Figure 2).**

Generally, two inflection points are observed in the strain gauge sensor and volume of sand production measurement in the ATWC test, (1) at the onset of sanding, and (2) at the catastrophic failure. ATWC test was carried out in this study shows that the first inflection point corresponding to the onset of sand production and the second inflection corresponds to the total failure /catastrophic failure (Figure 2).

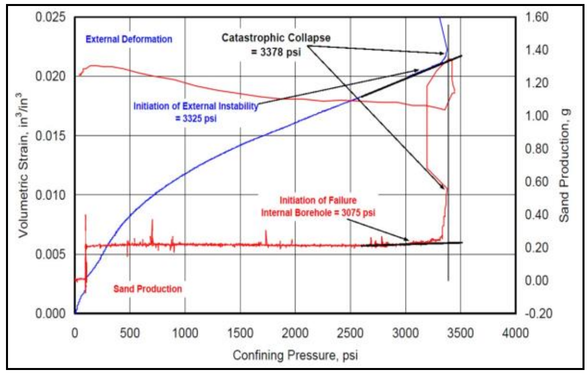

Figure 2: Plot of volumetric strain and sand produced during thick-wall cylinder test.

To investigate the effect of water production on the collapse pressure, TWC test was carried out on two samples of near equal depth. One of the samples was saturated with oil and another sample with formation fluid. The result indicates that water saturation decreases the catastrophic collapse strength by about 25% when compare to the strength obtain from oil saturated sample. The results were then integrated with prediction model to define the pressure limits for onset of sand production & catastrophic failure as well as to analyze the effect of water production on critical drawdown pressure for the producing wells.

Rock Strength Modeling:

Empirical relationship was established between core measured UCS and sonic velocity (DTCO) to generate the UCS profile across the target zone, which is as follows;

$$UCS = 130*(140-2.1*DTCO+0.0083*DTCO^2)... \quad (1)$$

Further ahead, a relationship between UCS and TWC is established based on the available laboratory test data to define the complete TWC strength profile for the target zone (**Figure 3**). The same relationship was then used to estimate the TWC strength for the producing wells.

Sub Surface Stresses and formation Pressure:

In this model, vertical stress (σ_v) at well locations was estimated using available density data. The minimum horizontal stress (Shmin) was estimated using Eaton (1969) method through the equation (2) and calibrated with available data (LOT/FIT) in the overburden as well as in the reservoir section;

$Sh_{min} = (v/1+v) * (\sigma_v - p) + p$ ………….. (2)

Where v is the Poisson's ratio and p is the formation pressure.

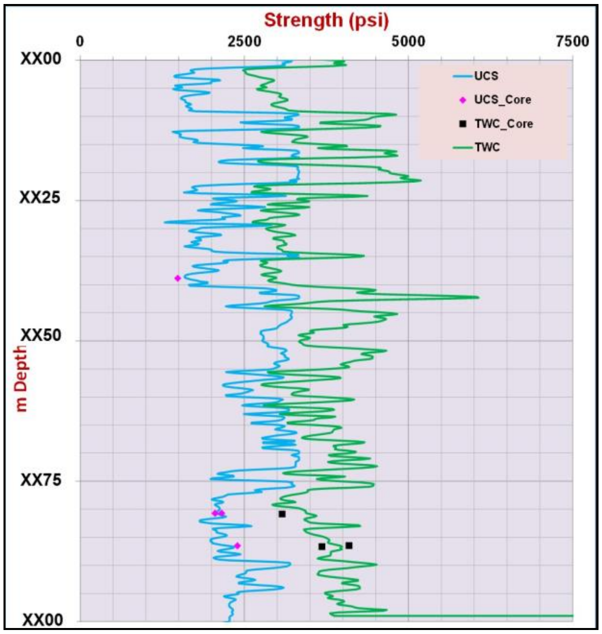

Figure 3: Rock strength profile for UCS and TWC strength calibrated with core.

Unlike minimum horizontal stress, direct measurement of maximum horizontal stress is not possible; however, it was inferred from the available caliper data showing breakout in the nearby offset wells. The direction of maximum horizontal stress was determined by breakout orientation observed in the offset well, major fault orientation and global stress database.

The initial reservoir pressure (p) was measured through the wireline formation pressure tester; however, in the depletion stage current reservoir pressure data (pr) was obtained from the downhole pressure gauge placed in the lower completion just above the reservoir top, where the shut-in data was taken for the stabilized formation pressure as current reservoir pressure rather than flowing dynamic pressure.

Effect of Pressure Depletion:

The depletion of reservoir pressure leads to a decrease in the magnitude of horizontal stresses within the reservoir, which is called as "stress path". However, the magnitude of decrease varies from field to field and is dependent on many parameters. In order to estimate the effect of depletion on the stresses, poroelastic theory (Segall and Fitzgerald, 1998) was used and calibrated with the well event (loss) happened during drilling the reservoir in the depleted condition (Dutta and Ashutosh, 2015; Dutta et al., 2018). The final estimated stress path after calibrating with well event is about 0.5, which indicates that 1 psi reduction in pore pressure cause 0.5 psi reduction in the minimum stress.

Sand Production Prediction Model: Methods & Results

Analytical sand production model can be divided into two broad groups: (1) model based on tensile failure criterion and (2) model based on shear failure criterion (Vaziri et al., 2002; Veeken et al., 1991; Sanfilippo et al., 1995; Palmer et al., 2003). According to the tensile failure model, if the given drawdown is higher than the tensile strength of rock, rock fails in tension and there will be sand production, which is best visualized in unconsolidated sands. However, practical use of this model is mostly in the optimizing early life drawdown and effect of depletion is not factored into this model (Vaziri et al., 2002).

In this study area, field is already depleted by about 45-50%, at the current reservoir stress state, shear failure is most likely to happen; hence, we have adopted the shear failure model. We have integrated the results of ATWC strength test with log data to predict the risk and magnitude of sand production at different depletion reservoir state. Three stages of sanding have been captured in the model based on the ATWC test results (Figure 4);

- Onset of Sand failure: It represents the initiation of failure from the intact sandstone with dis-aggregated zone around the wellbore. It can cause a problem when it is transported to the surface.
- Catastrophic Failure: It represents the pressure at which total failure occurs, it results in a high rate of sand influx into the

well. This phase of sand production is hard to manage and will adversely affect the subsurface and surface completion and production facilities.

- Water-Induced Sanding: The capillary forces holding the dis-aggregated particles get destroyed due to high water cut during production, which accelerates the sand failure even at early depletion stage.

Sand failure Initiation model:

The onset of sanding is being predicted using stress-strength based shear failure model around the open hole wellbore. The criterion for sanding (Palmer et al., 2002) described as:

CBHFP < $((3*S_2\text{-}S_3\text{-}S_y) / (2\text{-}A)) – P_r\ (A/2\text{-}A)$…..(3)

CDP = $(1/2\text{-}A) / (2*\ P_r – (3*S_2\text{-}S_3\text{-}S_y))$..........…(4)

$\boldsymbol{S_y} = 3.4*TWC$………………………………….(5)

Where CBHFP is the critical bottom hole flowing pressure, S1 and S3 are the principal major and minor stresses, Sy is the formation strength near the opening (3.4 times the TWC, where 3.4 is the scale factor determined for transformation of laboratory measurement to field scale, which was determined based on the sanding event experienced in the well A). Pr is the current reservoir pressure, A is the poro-elastic constant (stress path). CDP is the critical drawdown pressure, which is the available drawdown limit from the reservoir pressure beyond that shear failure is obvious.

The sand prediction model for well A at reservoir depletion of 45-50% from initial pressure indicate that around 5-6m of completed reservoir is having low strength (less than 1700 psi), which are already failed in shear failure mode (**Figure 4**) and no drawdown limit is available.

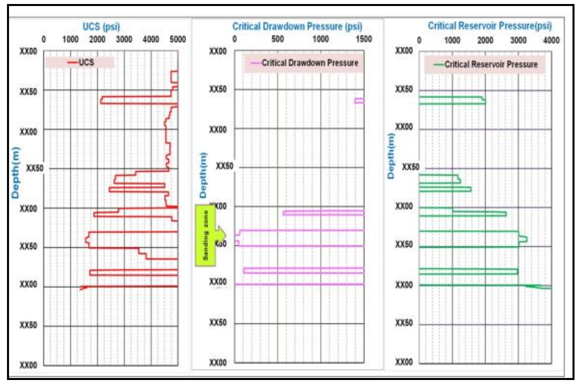

Figure 4: Sand failure initiation prediction model for well A.

The most part of completed interval (~70-80%) has drawdown limit of only about 100-150 psi, any drawdown above 150 psi will cause shear failure and hence sanding production; and may only be noticed when those failed sand transported to surface. In well A sand amount of about ~15.8 kg **(Figure 6)** was observed on surface by Clamp-On detectors when drawdown was increased above 200 psi.

Sand Catastrophic Failure Model:

Catastrophic sand failure was predicted using TWC collapse strength corresponding to total failure of internal boundary / high magnitude of sanding. Laboratory test shows that (Figure 2) measured TWC strength at the catastrophic failure is higher by about 250psi compared to onset of sand failure. The failure pressure initiation at external boundary (3325psi) was taken as TWC strength to predict the catastrophic sand failure of the same well A. The model shows a sand zone of low strength (5-6 m) will go into catastrophic or total failure if drawdown is higher than 400 psi (**Figure 5**).

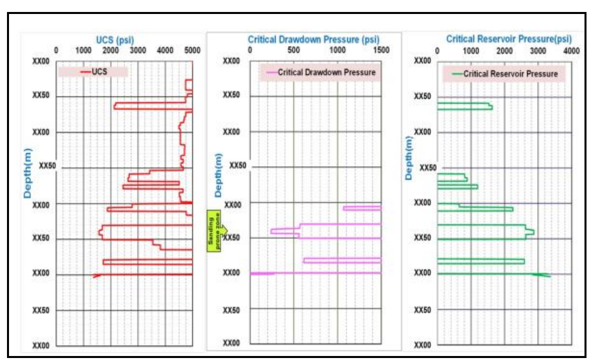

Figure 5: Sand catastrophic failure model for well A.

During the ramp of phase of well A drawdown levels went very high (350 to 400 psi) due to mechanical failure of subsea chokes .The amount of sand detected by Clamp-On sensors also increases from few kilos to hundreds of kilos after mechanical failure of subsea. The catastrophic sand failure model indicates, by drawdown of 300 psi some part (5-6 m) of the low strength rock formation have undergone catastrophic sand failure, which explains increased quantities of sand/solids (290-300 kg) detected by Clamp-On data sensors (**Figure 6**). The sanding event was experienced in well A was further categorized into two part depending on magnitude of sanding; (1) Sand failure initiation: where the amount of sand detected by Clamp-On sensors was less at lower drawdown, (2) Catastrophic Failure: in this case heavy amount of sand was detected by Clamp-On sensors at the higher drawdown **(Figure 6).** The predicted CDP in the well A for both sand failure initiation and catastrophic failure of completed interval is having good match with the actual sanding event.

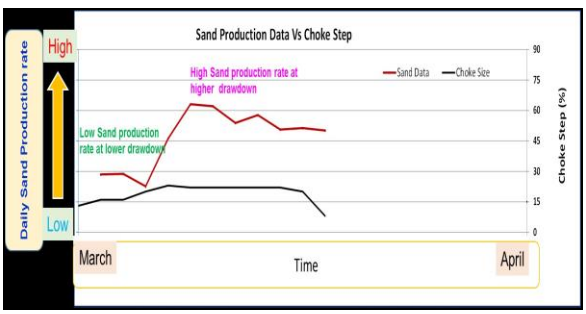

Figure 6: Well A sand production data.

This calibrated model with same calibrated parameters was run for the other producing wells to know more about the operating drawdown pressure limits for sand initiation and catastrophic sand failure. The maximum drawdown was decided based on catastrophic sand failure.

Water Induced Sanding:

Vaziri et al., 2002 and Han et al., 2004 explained how failed and disaggregated sand can be held together by capillary cohesion forces due to connate water with no water production, while water cut can significantly increases the sanding potential as it destroys the capillary forces and reduce the strength of reservoir. The wells which are having high water cut or located near water body is having higher risk of early sand production. The ATWC test have been performed at few reservoir sand samples (saturated with formation water in place of oil) to examine the effect of water ingress on TWC strength of reservoir sand. The results of ATWC test shows decease of TWC strength by about 25% compared to sample saturated with oil, and clearly indicates that sanding tendency will increase as water ingress in hydrocarbon saturated zone during production life of field.

The sand initiation shows that at current depleted reservoir pressure (45%) no shear failure is expected in any part of the completed reservoir interval (**Figure 7A**), minimum drawdown of 900-1000 psi is available for the weakest zone. As we can see that based on above model, we should not have any sand production from well B at this depletion (~45%). However, field observations suggest that this well produces episodic sanding with the increase in water production (Water Gas Ratio>100bbl/mmscf), so it was appropriate to model the effect of increased water cut. Subsequently, sand prediction model of the well B with high water cut has been modeled considering decrease in TWC strength **(Figure 7B).**

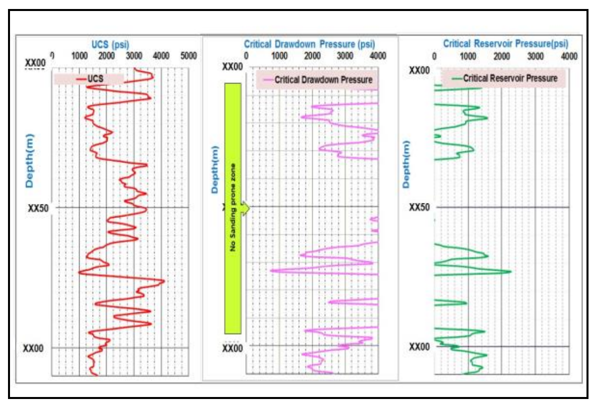

Figure 7A: Sand failure model of well B without water effect.

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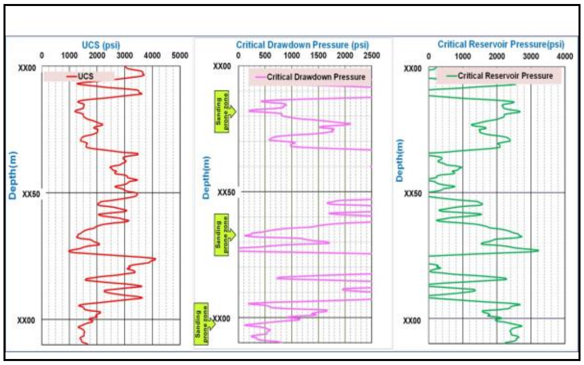

Figure 7B: Sand failure model of well B with water effect.

The sand failure model of well B, indicates that at the current depleted reservoir pressure (~45%), the weakest zone (5m interval) comes under sand failure initiation with given drawdown of around 100 psi (**Figure 7B**). Slight increase in drawdown will bring some additional zones to fail, which would be transported to the surface with water effect. This Well B has experienced episodic mild sand production, when there was increase in water production. The calibrated model was further used to identify the risk of sand production for upcoming planned wells located near water contact and edge water.

Conclusions:

In the study area, the reservoir is depleted up to 45-50% from the in-situ condition. This depletion has caused significant reduction in horizontal stresses due to high stress path (0.5). Horizontal stress reduction has initiated the shear failure of low strength sandstone intervals around the wellbore wall. High drawdown and water production have also enhanced the failure and transportation capacity of failed material. The sand prediction model which incorporate different stages (onset & total including effect of water on failure mode) will be helpful in effective sand management. The model highlights that the major controlling factor for the sand production in the study area are geomechanical parameters (rock strength, reservoir pressure, and stress), production parameters (water production, drawdown).

This sand prediction model has helped us for better sand management of already producing wells (with SAS technique) by optimizing the drawdown pressures. The completion strategy for the planned future wells were changed and decided to complete with open hole gravel packing to avoid the risk of sanding and sustain the well productivity.

References

Dutta, J. and Kumar, A., 2015, November. Application of Integrated Reservoir Geomechanics for Well Planning and Drilling of Nearly Horizontal Wells in a Depleted Reservoir of Offshore Krishna-Godavari Basin, India. In SPE Oil & Gas India Conference and Exhibition. Society of Petroleum Engineers.

Dutta, J., Kumar, A., Bhardwaj, N., Gunasekaran, K. and Mohammed, S., 2018, Production induced faulting risk assessment in a depleted reservoir: A case study from deepwater Krishna-Godavari basin, India. Journal of Petroleum Science and Engineering, 161, pp.319-333.

Han, G., Dusseault, M.B. and Cook, J., 2004, Why sand fails after water breakthrough. In Gulf Rocks 2004, the 6th North America Rock Mechanics Symposium (NARMS). American Rock MechKianics Association.

Lau, H.C. and Davis, C.L., 1997, Laboratory studies of plugging and clean-up of production screens in horizontal wellbores. In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.

Palmer, I., Vaziri, H., Willson, S., Moschovidis, Z., Cameron, J. and Ispas, I., 2003, January. Predicting and managing sand production: A new strategy. In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.

Vaziri, H., Barree, B., Xiao, Y., Palmer, I. and Kutas, M., 2002, January. What is the magic of water in producing sand?. In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.

Vaziri, H., Xiao, Y. and Palmer, I., 2002, Assessment of several sand prediction models with particular reference to HPHT wells. In SPE/ISRM Rock Mechanics Conference. Society of Petroleum Engineers.

Vaziri, H.H., Allam, R.D., Kidd, G.A., Bennett, C.L., Grose, T.D., Robinson, P.A. and Malyn, J., 2006. Sanding: A rigorous examination of the interplay between drawdown, depletion, start-up frequency and water cut. SPE Production & Operations, 21(04), pp.430-440.

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