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Dynamic wellbore modelling to study the impact of producing through a smaller diameter velocity string to delay the onset of liquid loading: A case study in the North Sea Region

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Introduction

Issues with Mature Gas Well Performance

- Natural reservoir depletion, results in reduction of gas flow rate overtime
- The existing production tubing is often sized too large for the late production life of the well
- This would lead to insufficient gas velocity to transport produced liquid to surface
- Gradual liquid drop out during production results in creation of a liquid column in the wellbore which eventually causes the well to cease flowing.

Recommended Solution

- Insertion of a velocity string and producing through a smaller diameter tubing will increase gas velocity which delays the onset of liquid loading

Subjects of the Study

- Analysing and identifying the optimum velocity string size
- Identifying the suitable velocity string conceptual completion design
- Evaluating the best conveyance / completion operations for installing the velocity strings
- The study included 4 candidate wells from which one example well will be presented here

Steady State Well Performance Modelling

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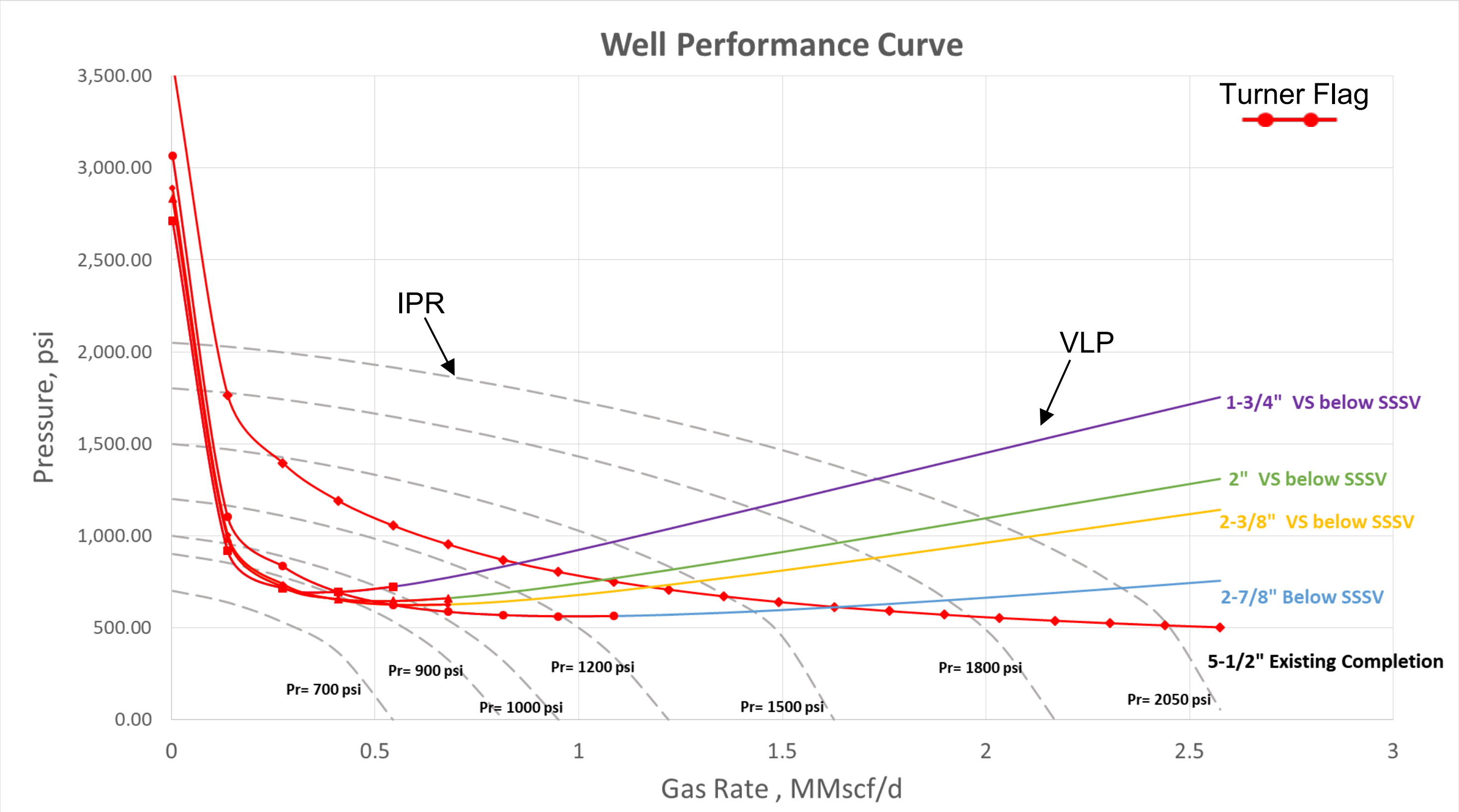
- The well in the subject reservoir is known for high liquid production (WGR of 50 stb/MMscf)
- Initially a steady state well performance model was created to assess the benefit of inserting a velocity string and producing through smaller ID tubing
- Turner velocity criteria calculated by the model defines the point in which the well is liquid loaded
  - ➢ Liquid loading occurs when gas velocity drops below the critical velocity (the Turner velocity)
- Results of insertion of velocity string showed attractive production gains by delaying the onset of liquid loading
- However,
  - some uncertainties on the Turner criteria remains due to steady state nature of the model and simplicity of the approach for such complex fluid dynamic phenomenon
  - also the results of this approach deemed inaccurate for the velocity string completion cases where the string is set below SSSV

➔ This triggered the OLGA dynamic wellbore study to accurately evaluate the benefit of inserting velocity strings

Example of Steady State Well Performance Model

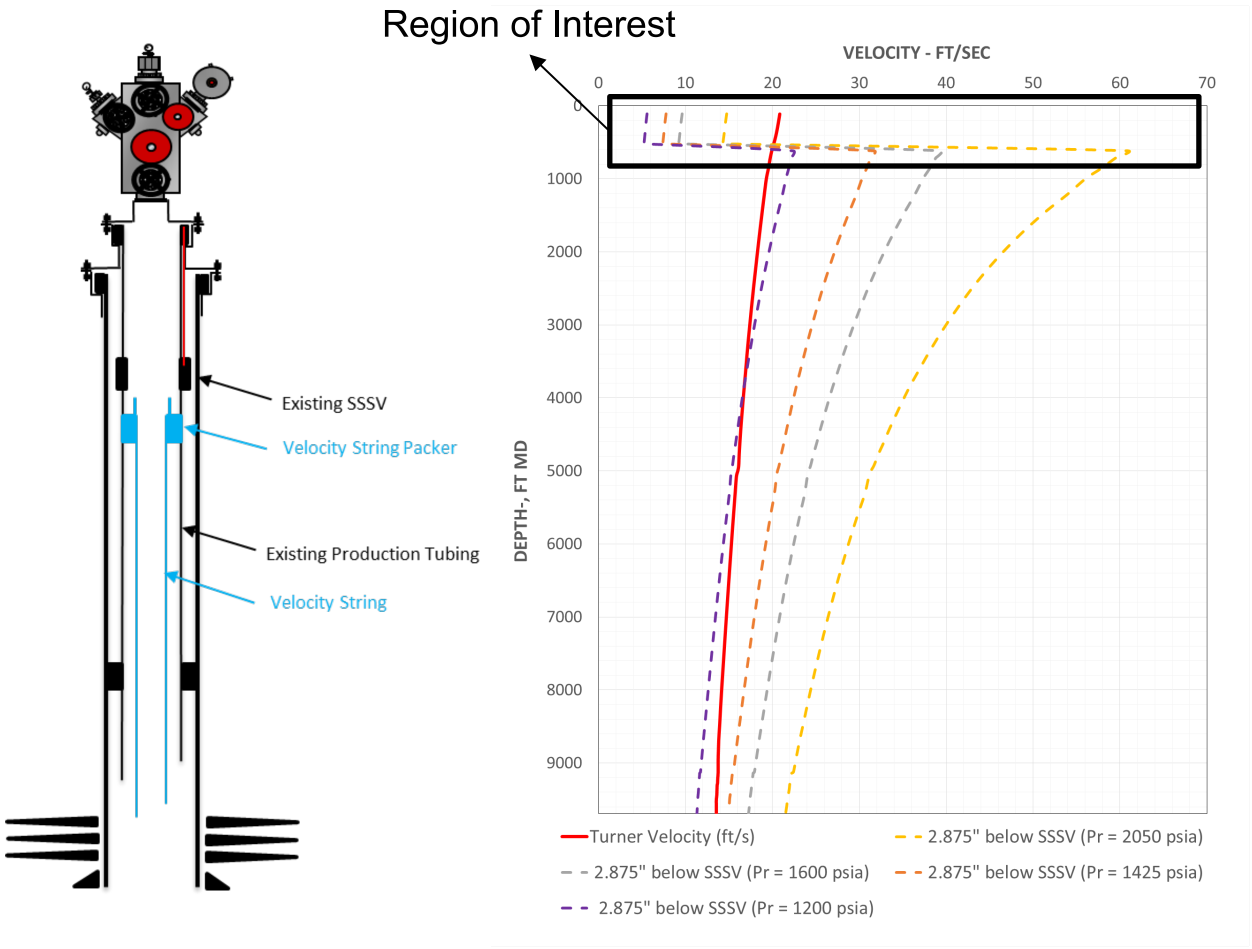


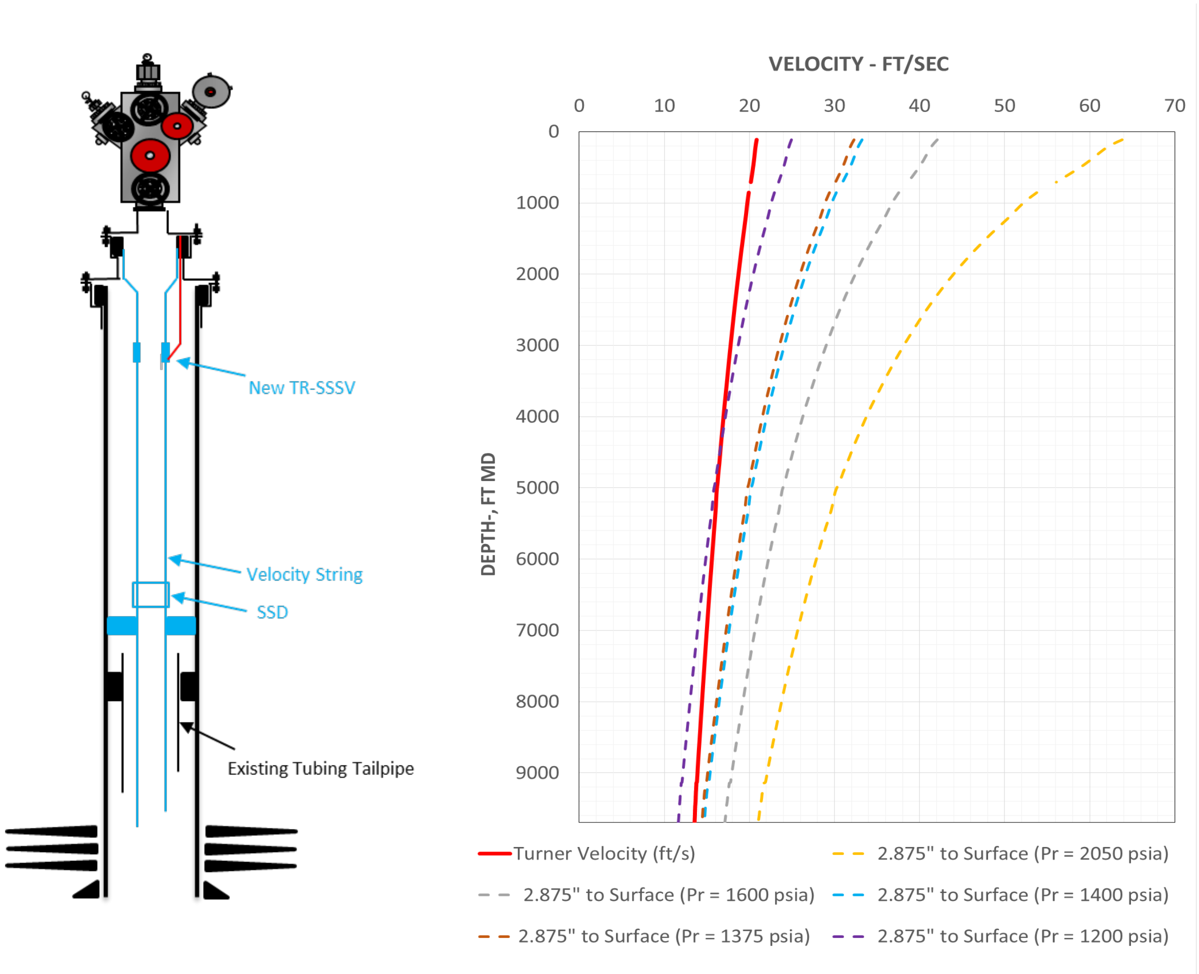
- The Intersection between the Inflow Performance Relationship (IPR) curve and Vertical Lift Performance (VLP) curve determines the flow rate
- The Turner flag points out the reservoir pressure in which the well is liquid loaded
- Sensitivity on reservoir pressure and tubing sizes performed
- Trade-off between production sustainability vs. reduction in flow rate

Cases	Initial Qg (MMscf/d) – 2050 psi Pr	Reservoir Pressure min before loading
Existing completion (5-1/2")	2.44	Already loaded @ 2050 psi
2-7/8" below SSSV	2.30	1200 psi
2-3/8" below SSSV	2.09	1050 psi
2" below SSSV	1.99	1050 psi
1-3/4" below SSSV	1.73	1000 psi

Increased reservoir depletion

Key Issue with the Steady State Modelling





- Setting velocity string below SSSV is the preferred completion option
- But what is the dynamic fluid behaviour above the velocity string ?
- Based on Turner criterion well would liquid load above the top of velocity string → Accuracy ?

- Although there is no discontinuity in velocity profile in this completion, the Turner approach needed verification due to its mathematical simplicity
- The completion option is not preferred due to high cost of installation

Velocity String Selection Workflow

Build OLGA transient well models → Match behaviour of each dynamics well performance with field data → Sensitivity analysis on reservoir pressure → Sensitivity analysis on string size and length (set below SSSV vs. extension to surface → Identify min reservoir pressure at which each well is liquid loaded

Create matching Prosper models with the OLGA results → Build MBAL models and history match → Generate production forecast for different completion scenarios → Production cut off observed from min reservoir pressure determined by OLGA results

Review of possible conceptual velocity string completion designs → Peer review of completion design and operations → Cost evaluation and risk review of all options → Detailed cost analysis for the recommended options

Detailed economics modelling for each option → Conclusion and Recommendation

OLGA Modelling Input

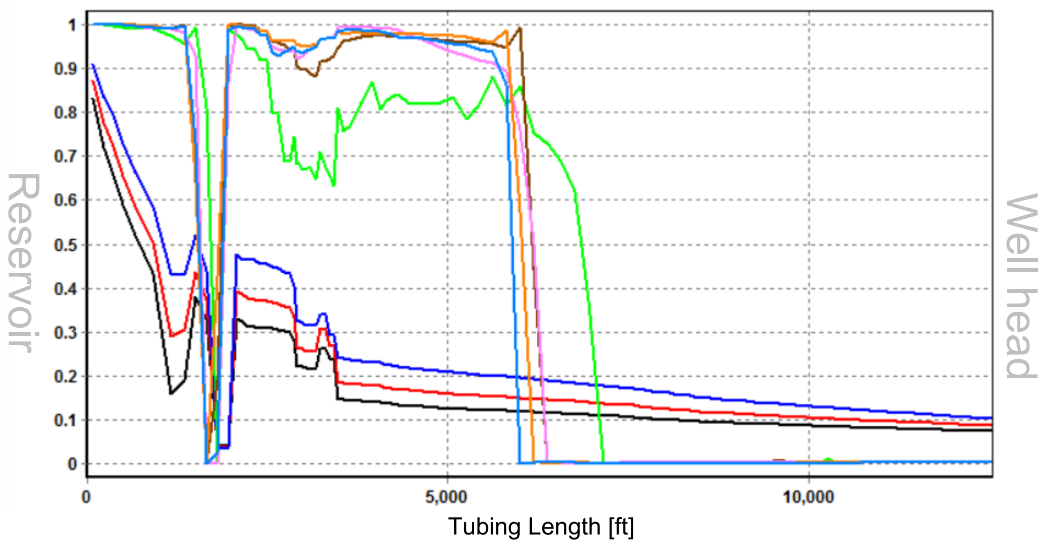
- FLUID: BLACKOIL fluid modelling was used consistent with field PVT
- GEOMETRY: Horizontal legs also modelled to increase accuracy of initialisation and liquid hold-up.
- OUTLET BOUNDARY PRESSURE = 14 barg
- AMBIENT TEMPERATURE AT SURFACE = 48°F
- AMBIENT TEMPERATURE AT RESERVOIR = 188°F
- RESERVOIR PROPERTIES = Backpressure IPR model (C = 27.5 scf/d/psi^2 , n = 0.75)
- INITIAL CONDITIONS = The Steady State Pre-Processor was used to initialise the models, followed by a dynamic transient simulation.
- SIMULATION TIME = 3 days
- WGR = 50 stb/MMscf

OLGA Results for Existing 5.5" Completion

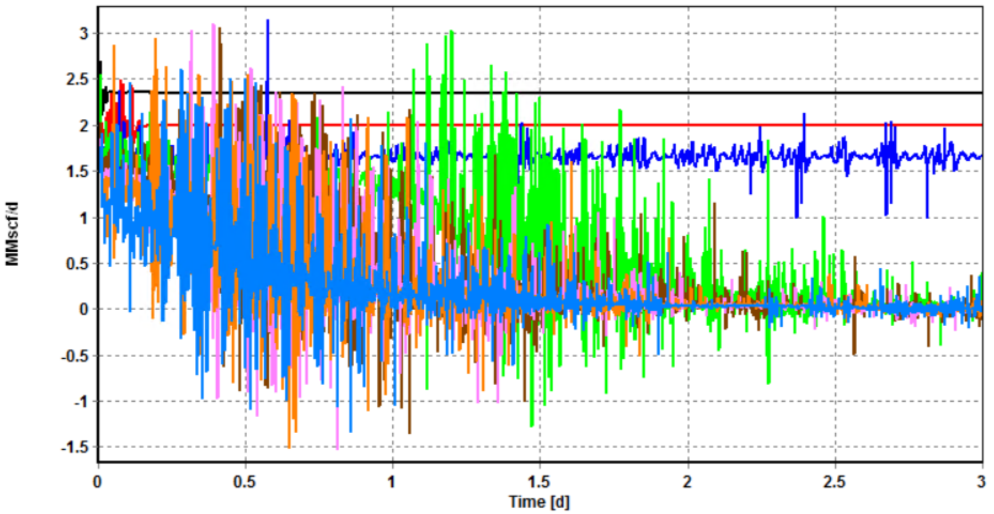
- The plots below show the transient gas volumetric flow rate at standard conditions and liquid hold up in the wellbore.
- At Reservoir pressures 2050, 1900 and 1800 psia, the gas well was able to flow at steady state. Below 1775 psia, the gas flow rates reduced to zero.

Reservoir Pressure [psia]	Gas [MMscf/d]
2050	2.35
1900	1.99
1800	1.69
1775	0
1750	0
1725	0
1700	0
1600	0

Liquid holdup



Gas Flow Rate

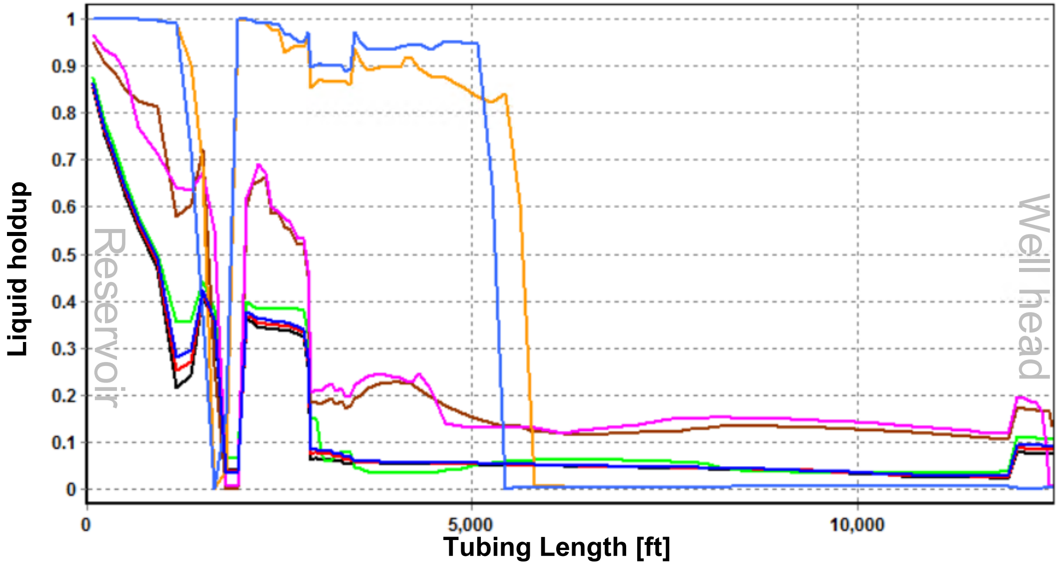


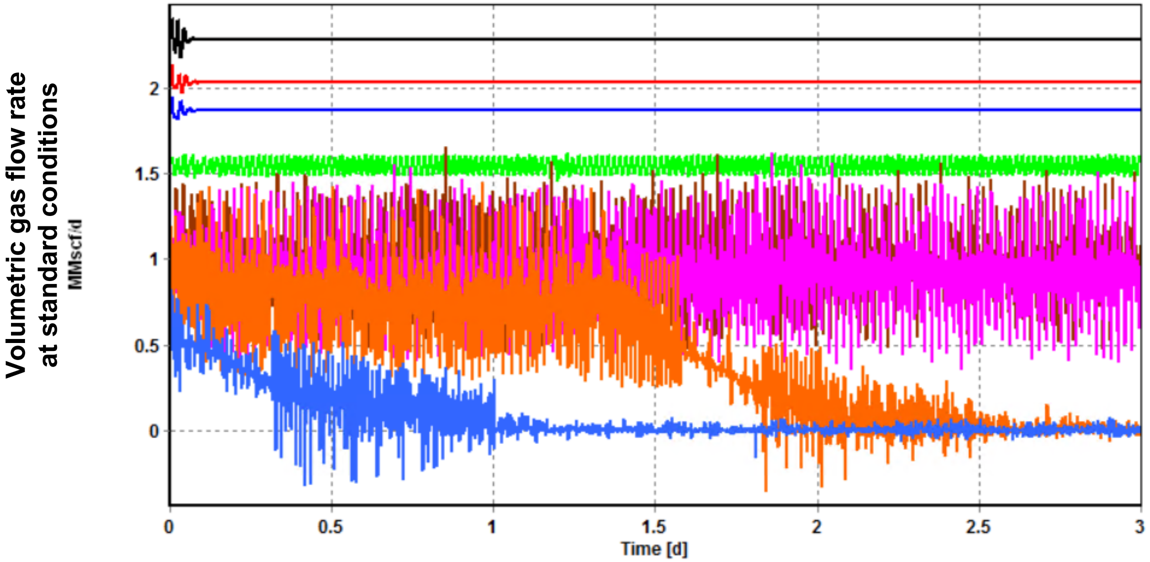
OLGA Results for 2.875" VS below SSSV

- The plots below show the transient gas volumetric flow rate and liquid hold-up at standard conditions.

- At Reservoir pressures above 1425 psia, the gas well was able to flow at steady state. Below 1400 psia, the gas flow rates reduced to zero.

Reservoir Pressure [psia]	Gas [MMscf/d]
2050	2.28
1900	2.03
1800	1.87
1600	1.55
1450	1.02
1425	0.91
1400	0
1300	0





OLGA Results for 2.875" VS to Surface

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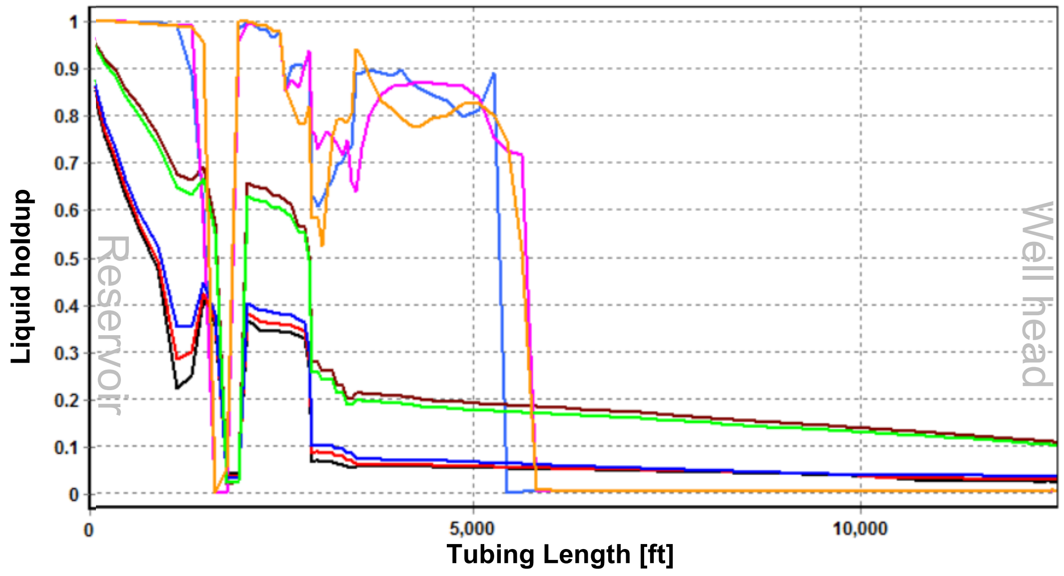
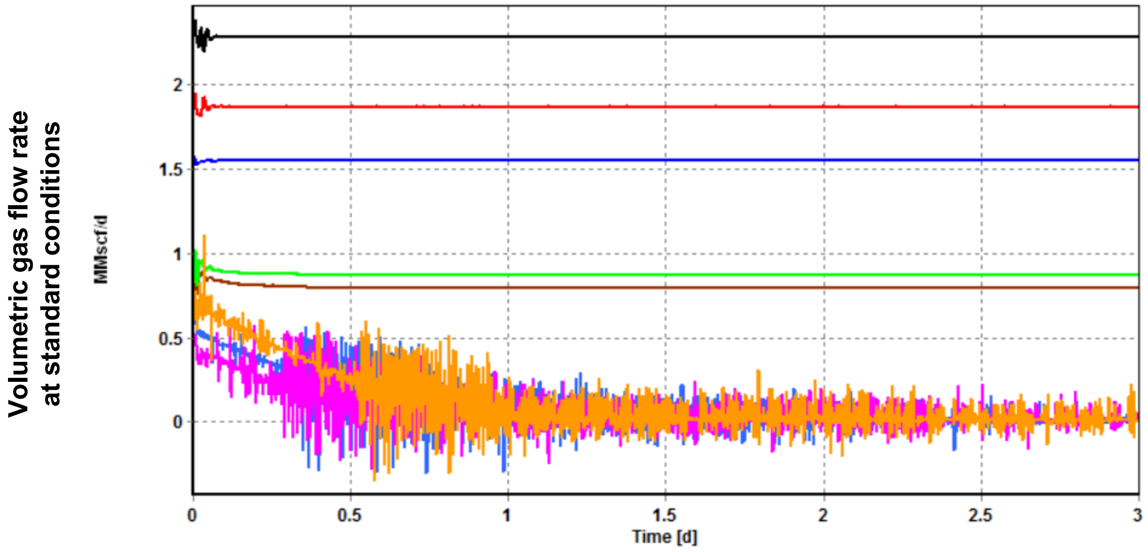
- The plots below show the transient gas volumetric flow rate at standard conditions and liquid hold-up
- At Reservoir pressures above 1375 psia, the gas well was able to flow at steady state. Below 1350 psia, the gas flow rates reduced to zero



Reservoir Pressure [psia]	Gas [MMscf/d]
2050	2.28
1800	1.86
1600	1.54
1425	0.87
1375	0.79
1350	0
1300	0
1200	0



OLGA vs. Steady State Well Model

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2-7/8" Velocity String below SSSV				
Reservoir Pressure [psia]	OLGA Q-Gas [MMscf/d]	SS Q-Gas [MMscf/d]	Prosper Turner Flag	Prosper Turner Nodal flag
2050	2.28	2.30	No	Yes
1800	1.87	1.88	No	Yes
1600	1.55	1.55	No	Yes
1450	1.02	1.32	No	Yes
1425	0.91	1.27	No	Yes
1400	0	1.24	No	Yes
1375	0	1.20	No	Yes
1350	0	1.16	No	Yes
1300	0	1.08	Yes	Yes
1200	0	0.93	Yes	Yes

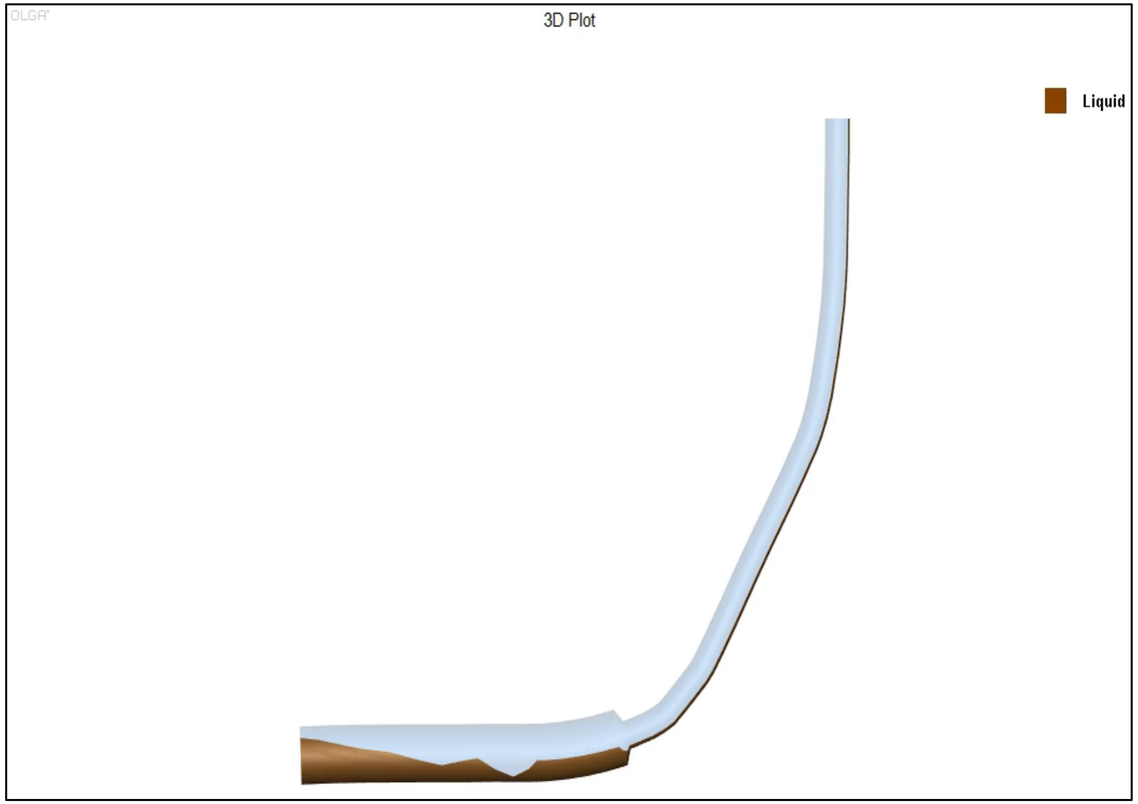
2-7/8" Velocity to Surface				
Reservoir Pressure [psia]	OLGA Q-Gas [MMscf/d]	SS Q-Gas [MMscf/d]	Prosper Turner Flag	Prosper Turner Nodal flag
2050	2.28	2.29	No	No
1800	1.86	1.87	No	No
1600	1.54	1.54	No	No
1450	1.01	1.32	No	No
1425	0.90	1.28	No	No
1400	0.87	1.24	No	No
1375	0.79	1.21	No	No
1350	0	1.16	No	No
1300	0	1.09	Yes	Yes
1200	0	0.94	Yes	Yes

OBSERVATIONS

- Note that OLGA rates drop when IPR intersecting unstable region of the dynamic VLP (minima) due to commencement of erratic flow behaviour which is not captured by the steady state model
- Although steady state model solves the system calculation at much lower reservoir pressure but the Turner flag determines when the well will start liquid loading
- Turner criterion could be acceptable for the velocity string extended to surface, but either too **optimistic or not predictive for the case below SSSV**

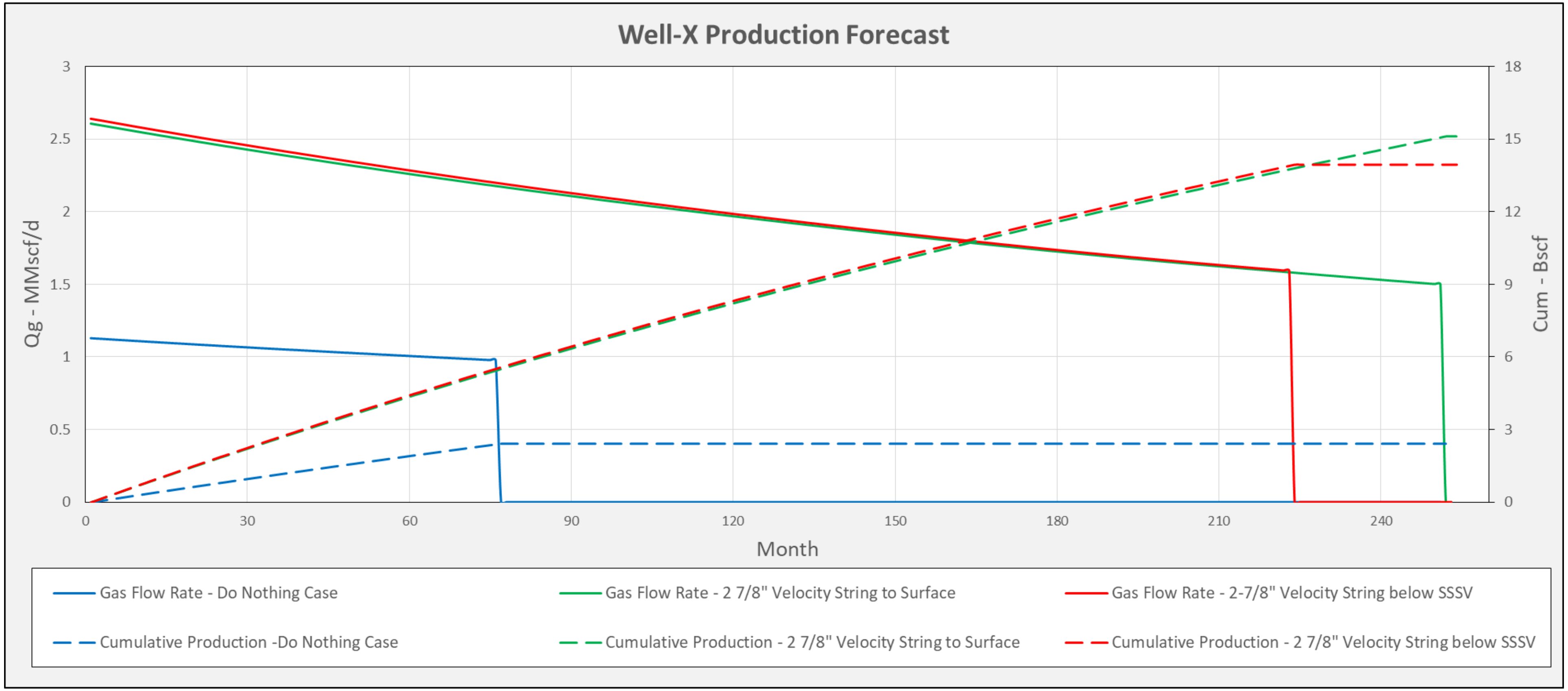
OLGA Results Summary

Reservoir Pressure [psia]	Base Case (Existing completion) Status	2.875" VS up to SSSV Status	2.875" VS up to Surface Status
2050	Flowing	Flowing	Flowing
1800	Flowing	Flowing	Flowing
1775	Liquid Loaded	Flowing	Flowing
1750	Liquid Loaded	Flowing	Flowing
1725	Liquid Loaded	Flowing	Flowing
1700	Liquid Loaded	Flowing	Flowing
1600	Liquid Loaded	Flowing	Flowing
1450	Liquid Loaded	Flowing	Flowing
1425	Liquid Loaded	Flowing	Flowing
1400	Liquid Loaded	Liquid Loaded	Flowing
1375	Liquid Loaded	Liquid Loaded	Flowing
1350	Liquid Loaded	Liquid Loaded	Liquid Loaded
1200	Liquid Loaded	Liquid Loaded	Liquid Loaded



Production Forecast Methodology

- Steady state well models were generated matching the transient wellbore modelling results
- Reservoir material balance model created and used to generate the production forecast
- The benefit of velocity string is the production gains in comparison with "Do Nothing":
  - ➢ This approach allows comparison of different completion methods (below SSSV vs. to Surface)
  - ➢ Allows economical calculations and strategic decision making.



Conclusion

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- The study showed the limitations of steady state wellbore modelling for assessing the impact of velocity string
  - ➢ The reliability of this approach was questionable when there is a discontinuity in the velocity profile due to step completions e.g. setting velocity string below SSSV
  - ➢ Use of Turner criterion for determining the onset of liquid loading showed optimistic results in comparison with dynamic wellbore modelling results

- Dynamic wellbore analysis showed that the models for the existing completions replicated the flow behaviour and pressure signatures observed in the field data

- With insertion of velocity string and producing through a smaller diameter velocity string the well was able to flow at lower reservoir pressure

- The difference in production gain between setting a velocity string below SSSV or extending to surface were marginal to justify an economic case for a full workover to allow completion to surface