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Designing Coiled Tubing Velocity Strings

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Summary

Many flowing oil and gas wells experience decreased production over time, and eventually can stop producing completely. Factors causing this problem include declining reservoir pressure and gas velocities, and increased water production. Increased water production can also cause a column of water to accumulate at the bottom of the well, preventing reservoir fluids from entering the wellbore. This accumulation of water is called “liquid loading of the well”.

One method of restoring a well that is “liquid loaded” back to flow production is installing a smaller diameter coiled tubing string (velocity or siphon string) inside the production tubing.

Numerous parameters (current and future reservoir pressures, liquid and gas production rates, CT diameter and depth, wellhead and flowing bottomhole pressures, etc.) govern the performance of a velocity string. To evaluate if velocity string design will return a loaded well to flowing production and how long it will sustain production, you compare the reservoir inflow performance with the tubing outflow performance.

How a Velocity String Works

The rationale behind installing a coiled tubing string of smaller diameter than the production tubing is to reduce the cross-sectional flow area. The smaller cross-sectional flow area increases the gas velocity in the tubing. The higher gas velocity at the bottom of the tubing provides more transport energy to lift liquid up out of the well. Liquid no longer accumulates at the bottom of the well, and production is sustained.

The gas velocity must meet or exceed a minimum or critical velocity to prevent a well from loading up. There are two popular methods for determining the minimum gas velocity: a "rule of thumb" widely accepted in the petroleum industry, and a theoretical correlation presented by Turner *et al.* (1969)*.

The "rule of thumb" sets the minimum gas velocity at 10 ft/sec. Thus, a well can be restored to flowing production if the gas velocity at the bottom of the tubing remains above 10 ft/sec.

The correlation presented by Turner *et al.* (1969) uses a theoretical analysis of the flow regime. In order to prevent liquid loading of the well, the liquid in the tubing must be suspended as a mist (qualities above 95%) or the flow regime in the tubing must be in annular-mist flow. In these flow regimes, as long as the gas velocities exceed the settling velocity of liquid droplets, high gas velocities force the liquid out of the tubing.

Designing a Velocity String

The objective of a velocity string design is to find an optimum coiled tubing size and depth that will restore the well back to flowing production, so that the frictional pressure losses in the tubing are minimal, and production is maximized. The well should also continue producing long enough to offset the cost of installing the velocity string.

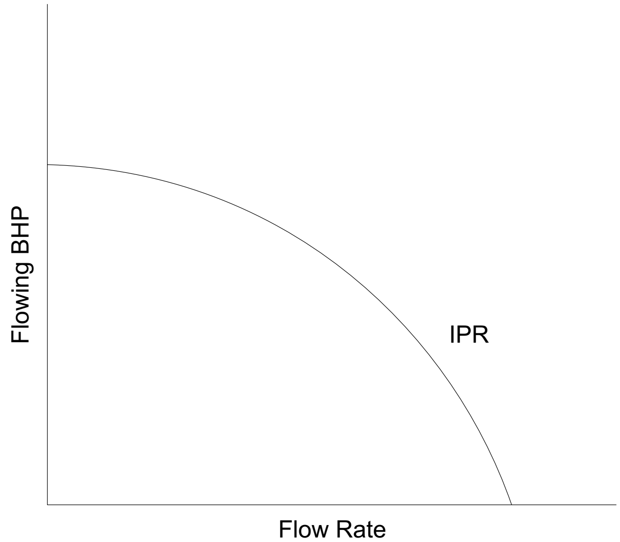
To design a velocity string that will return the well to flowing production and how long it will sustain production, you compare two curves:

- the reservoir inflow performance relationship (IPR), which describes the performance of gas flowing in from the reservoir.
- the tubing performance characteristic (J-curve), which describes the performance of gas flowing up the tubing.

* Turner, R. G., Hubbard, M. G., and Dukler, A. E.: "Analysis and Prediction of Mininum Flow Rate for the Continuous Removal of Liquid from Gas Wells," J. Pet. Tech. (Sept. 1969) 1475-1481.

Reservoir Performance

The reservoir inflow performance relationship (IPR) shows the relationship between the flowing bottomhole pressure and the gas flow rate from the reservoir into the well.

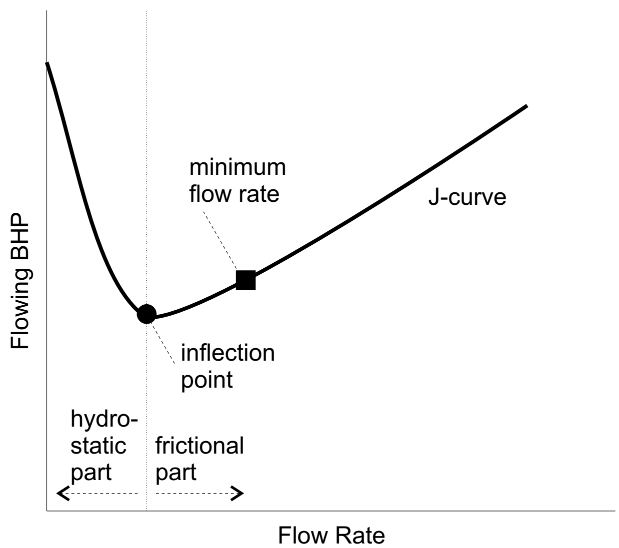


There are various methods available in the literature to construct the reservoir IPR for oil and gas wells. Cerberus constructs the reservoir IPR based on Darcy's equation for oil wells. This can be somewhat of a limitation since many velocity strings are installed in gas wells with high gas-liquid ratios (GLRs).

Note that the IPR is determined completely by the properties of the reservoir, especially the reservoir pressure. It is independent of the tubing performance curve.

Tubing Performance

The tubing performance curve describes the performance of a specific tubing size, depth, and wellhead conditions. As such, it is different for each velocity string design. This curve shows the relationship between the flowing bottomhole pressure and the gas flow rate up the well. It is called the "J-curve" due to its shape.



The J-curve is divided into two parts by the inflection (loading) point, where the slope is zero. To the left is the hydrostatic contribution. To the right is the contribution from tubing frictional losses. The minimum flow rate corresponding to the minimum velocity (as determined by the 10 ft/sec. rule of thumb or the Turner *et. al.* (1969) correlation) also appears on the J-curve.

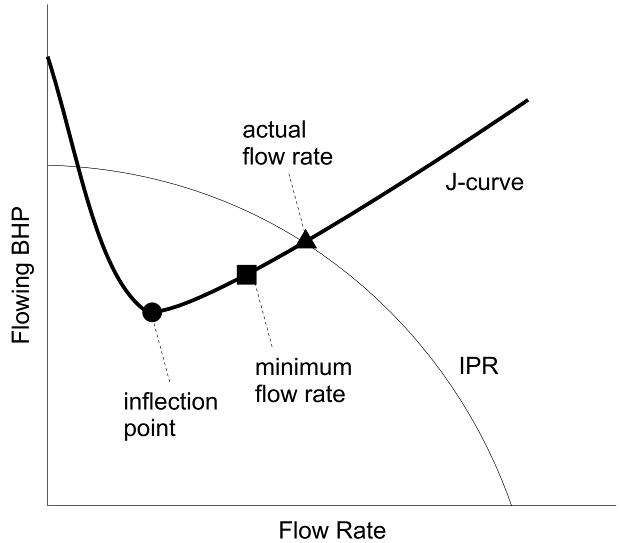
There are numerous multiphase models available to obtain the tubing performance curve in oil and gas wells. Cerberus uses multiphase models developed for oil wells and their predictions are generally good (errors less than 20%) up to a GLR of about 5000. Note that each model only applies to specific conditions, and select the model accordingly.

Evaluating a Design

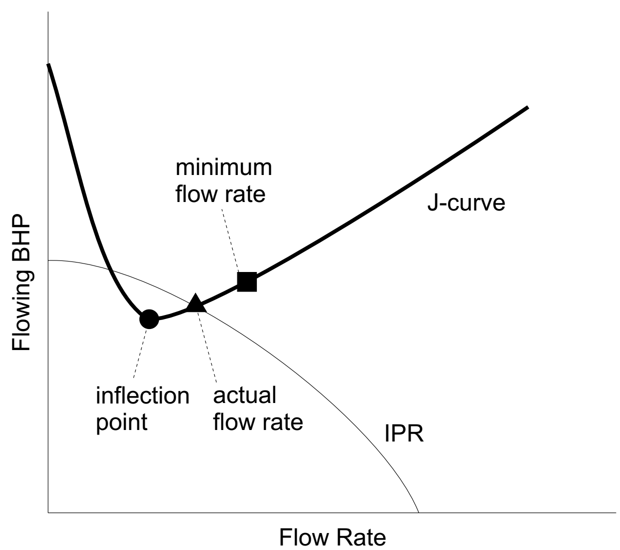
A well flows at the flow rate where its IPR and J-curve meet. Compare this intersection point with the minimum gas flow rate on the J-curve to see which of three situations will occur:

- the well will flow, without loading up
- the well will flow, but will load up and eventually stop producing
- the well will not flow

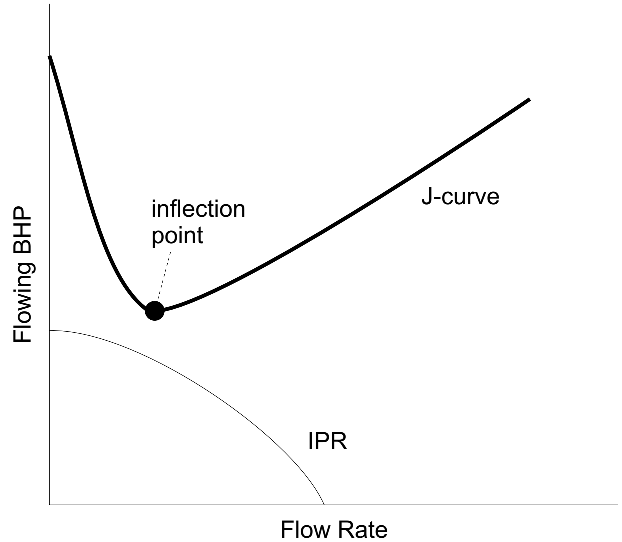
If the intersection point is to the right of the minimum gas flow rate, the well flows faster than the minimum gas flow rate and no liquid loading occurs.



If the intersection point is between the inflection point and the minimum gas flow rate, liquid loading occurs. The well flows, but will eventually kill itself.

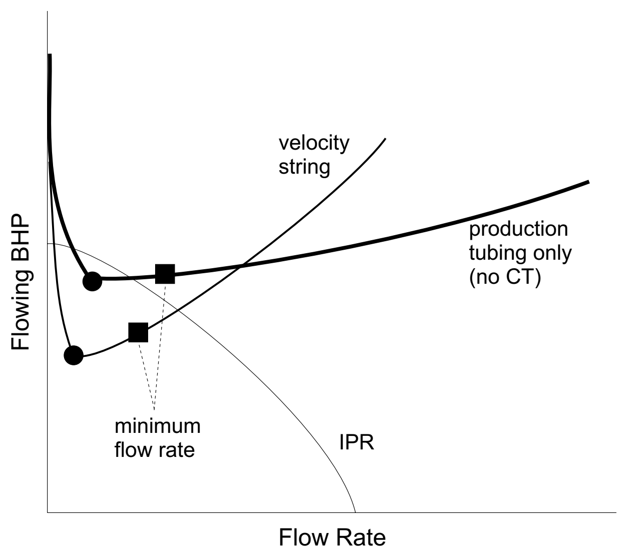


If the IPR and J-curve do not intersect, or if they intersect to the left of the inflection point, the flowing bottomhole pressure is too low for the well to flow for that particular tubing size, depth, and wellhead pressure. You should consider another velocity string design.

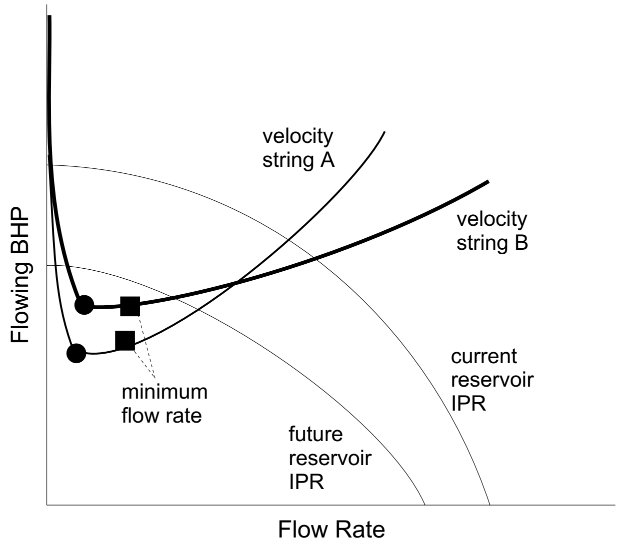


Comparing Multiple Designs

It is important to first evaluate the performance of the existing production tubing by itself to justify installing a velocity string. To evaluate the existing production tubing by itself, simply create the J-curve for the existing tubing with “no CT” installed and compare it with the IPR. If the well has already started to load up, you should install an appropriate velocity string before the well kills itself.



It is also important to make sure the velocity string design will keep the well flowing long enough to recoup the cost of the installation, as the reservoir pressure continues to drop. To see the future performance of the velocity string, create the IPR for the predicted future reservoir pressure and compare it with the J-curve of the velocity string. Make sure that the actual flow rate at the future pressure is still greater than the minimum flow rate.



If multiple designs will prevent the well from loading up, the optimum choice is typically a trade-off between current production (a higher flow rate) and sustained production (a lower bottomhole pressure).

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