An alternative to Turner for modeling liquid unloading?

Matt Dunning, BP - Southern North Sea
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Background to Project

• In several wells in BP SNS we are seeing liquid loading in wells which should not suffer from liquid loading according to conventional Turner / Coleman modelling

• Discussing with various engineers revealed varying views about application of Turner / Coleman
  – Use downhole or surface?
  – Use in deviated wells?

• As a result of this, BP suggested an MSc project for a student at Robert Gordon’s University Aberdeen for Summer 2008. Study comprising;
  – Literature search of previous work
  – Application of theory to practical applications and comparison of results

• This presentation represents the work of Asif Abbas for his MSc thesis
  – Asif unable to present this paper himself this week so you’re stuck with me!

• The work / results in this project are preliminary and require further work to validate – however the findings to date are interesting and we felt worthy of discussion
This presentation is an extension of the analytical model put forward by Mr. Guo, B. et al. 2006 (SPE-94081)

Preliminary conclusions from project:

- The current industry method of predicting the critical production rate may lead to underestimated values – especially for deviated wells
- Modification on the value of drag coefficient in Guo et al.’s original model resulted in better accuracy when applied to Turner et al.’s 106 field data points than either Turner’s correlation or Guo’s original
- Guo et al’s model seems to more closely match field production data for 2 BP deviated wells but further work is required before any firm conclusions can be made
The physics of Turner

- Liquid loading is defined as the inability of the gas to transport liquids coproduced to the surface.
- Turner’s model assumes critical velocity is the velocity at which drag forces and gravitational forces are balanced:

\[
V_C = 1.297 \left( \frac{\rho_l - \rho_g}{C_d \rho_g^2} \sigma \right)^{1/4}
\]

- For deviated well this has been adapted:

\[
V_c = 1.297 \left( \frac{\sigma (\rho_l - \rho_g)}{C_d \rho_g^2 \cos \theta} \right)^{1/4}
\]

(Flores, 2002)
Turner validation

- Turner et al.'s droplet model was proved based on 106 field data points
- The assumed drag coefficient was 0.44
Several published weakness in Turner’s original modelling

- Nossier (2000) showed Turner’s assumption of drag coefficient to be erroneous
  - 0.2 should have been used rather than 0.44 which may explain why a 20% adjustment was required to match field data
  - Data set used by Coleman et al (1991) had a different Reynolds number typically for which 0.44 was a more valid assumption – hence why 20% adjustment was removed
- Unable to cope with multi-phase flow – can only deal with gas and water OR gas and condensate (unable to deal with gas, water and condensate)
- Transport velocity (velocity required to carry the droplet to surface) not considered in the critical velocity equation by Turner
- In the droplet model the gas density varies 0.0031 times the gas pressure – this may be inaccurate for multiphase flow
- No consideration of liquid droplet deformation as a result of fore and aft pressure differentials (Turner / Coleman assumed spherical droplet)
An alternative to Turner?

- Guo et al published an alternative liquid transport model in 2006 (SPE 94081) – however the original error of drag coefficient 0.44 was perpetuated from Turner
  - Model based on the principle that the gas kinetic energy must exceed a minimum value to transport the liquid droplets
  - Minimum kinetic energy criterion is applied to a three-phase model
  - Model addresses some of the weaknesses of Turner but still uses some of the Turner theory (addresses transport velocity, multiphase pressure calc, 3-phase)
  - Model capable of dealing with deviation but not applied in Guo’s paper

- Abbas for this project uses Guo but modified for drag coefficient 0.2 (referred to as “Modified Guo’s model”) resulting in minimum kinetic energy:

  \[ E_{km} = 0.0842 \sqrt{\frac{\sigma \rho_l}{\cos \theta}} \]

- Comparing with the present kinetic energy at points in the wellbore determines the critical rate to lift liquids. Present kinetic energy:

  \[ E_k = 9.3 \times 10^{-5} \frac{S_g T Q_g^2}{A_i^2 p} \]
Turner Model vs Field Data

Field data is 106 points used in Turner’s original derivation
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Modified Guo et al.’s Model vs Field Data

Field data is 106 points used in Turner’s original derivation.
Conclusions?

- Guo / modified Guo seems to give a better fit to the 106 original data points used in Turner’s original work.
- Modifying Guo with lower drag coefficient leads to zero errors in predicting loaded-up or nearly loaded-up wells but does classify more unloaded wells as loading.
- All of this only looks at vertical wells…

<table>
<thead>
<tr>
<th>Condition of well</th>
<th>Error %</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Turner</td>
</tr>
<tr>
<td>Loaded-up</td>
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<tr>
<td>Unloaded</td>
<td>2.00</td>
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<tr>
<td>Nearly Loaded-up</td>
<td>33.33</td>
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Deviated Wells?

- Original Turner data set does not contain deviated wells
- Coleman / Turner modified for deviation by Flores in 2002
- Guo model incorporates ability to deal with deviated wells
- Most BP SNS wells are deviated
  - How much difference does deviation make?
  - How do models compare with field data?
  - Applied to 2 case studies…
Case Study 1

- Offshore dry gas well
- 10,200 ft TVD, 12,600 ft MD depth, max deviation 53 degrees
- Current production ~2.5 mmcf/d
- Well frequently cycled to produce

Guo model seems to provide a possible answer to the cause of liquid loading for this well…?

Guo (modified) suggests would experience liquid loading due to deviation

NB small length of liner whilst suffering liquid loading in all models is of insufficient delta P to impact production
Case Study 2

- Offshore dry gas well
- 10,450 ft TVD, 11,200 ft MD depth, max deviation 53 degrees
- Current production ~3.5 mmscf/d
- Well cycled to produce

Guo model is closer to providing an answer to the cause of liquid loading for this well…?

Guo (modified) suggests would NOT experience liquid loading due to deviation… but closer to liquid loading point than other models

NB small length of liner whilst suffering liquid loading in all models is of insufficient delta P to impact production
• There is some evidence that commonly used Coleman / Turner correlations under-predict liquid loading in vertical wells and that Guo’s correlation may present a more accurate fit

• The published adaptation to Coleman for deviation does not seem to make much difference in terms of critical loading rate for the wells examined

• In comparison, Guo’s model applied to deviated wells predicts a significantly higher critical rate which matches field data more closely

• However…
  – This work has only been applied to 2 wells so far – further correlation with field data is required to validate this model further!!
Author’s Details:

• ASIF ABBAS
• E-mail: asifabbas78@hotmail.com