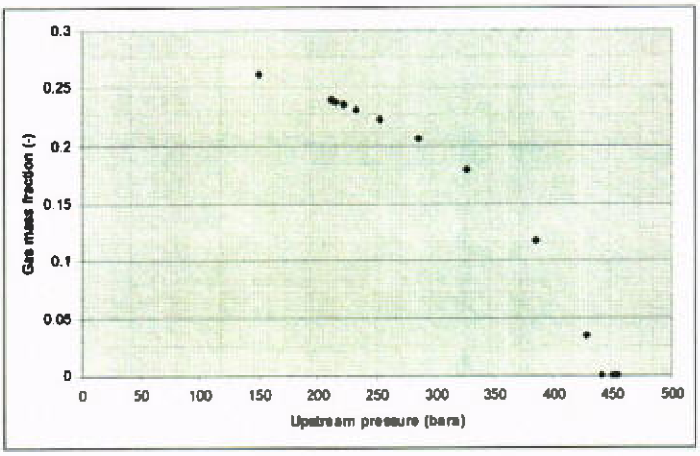
Dear Wayne

The information from the choke manufacturer states that the openings in the choke valve are equivalent to a circular hole of 0.0984 m (approximately 4"). Both the upstream and downstream piping is smaller than this (3" diameter), and there is also a restriction (the gasket) of 2.53" diameter upstream of the choke. The cross sectional flow area of the upstream restriction is 42% of the maximum choke opening, and the 3" diameter pipes have a cross sectional area of 60% of the maximum choke opening. Based on this the flow rate becomes less sensitive to changes in choke openings larger than approximately 50%.

Flash calculations using the PVTSim file show that the gas mass fraction at inlet to the flow geometry varies from 0 to 24 weight%, depending on the pressure. (See attached diagram.) According to my calculations 23 weight% corresponds to the specified 2900 standard cubic feet of methane per stock tank barrel of oil.



Calculations with a stand alone Hydro choke model have been made with the following assumptions:

- Inlet diameter 3".
- Outlet diameter 3".
- Upstream pressures from the specified table.
- Choke openings from the specified table.
- Upstream temperature 82.2 C.
- Choke diameter 0.0984 m.
- Cd = 0.6
- Downstream pressure 150.9 bara (2189 psia).
- Oil and gas properties are functions of (p, T) generated from PVTSim description.

Comment [SSO1]: Tror det er denne antagelsen som gir så rare og tilsynelatende ufysikalske resultater.
1) I et rørsystem som her kan multiple chokes forekomme, dvs man får kritisk strømning i mer enn ett tverrsnitt. Det lengst nedstrøms vil da bestemme massestrømmen. Underveis kan det være omslag til supersonisk og sjokk. En modell av dette må tillate implisitt løsning av multiple choking slik den gjorde som vi laget i et EU-prosjekt på midten av 90-tallet.
2) Hvis det ikke er tilstrekkelig restriksjon (dissipasjon av stagnasjonstrykk, friksjon) oppstrøms utløpet i havet, så vil strømningen choke der røret er åpent ut i havet. Massestrømmen bestemmes her. Trykket i utløpet vil være større eller lik trykket i havet, og man får ytterligere dissipasjon i form av skrå/normale sjokk i en jetstråle ut i havet.

- Upstream gas mass fraction determined from flash calculations to upstream (p, T).
- Maximum effective choke opening has been set to 50%. This means that only changes in upstream pressure and gas mass fraction affect the cases with choke opening larger than 50%.

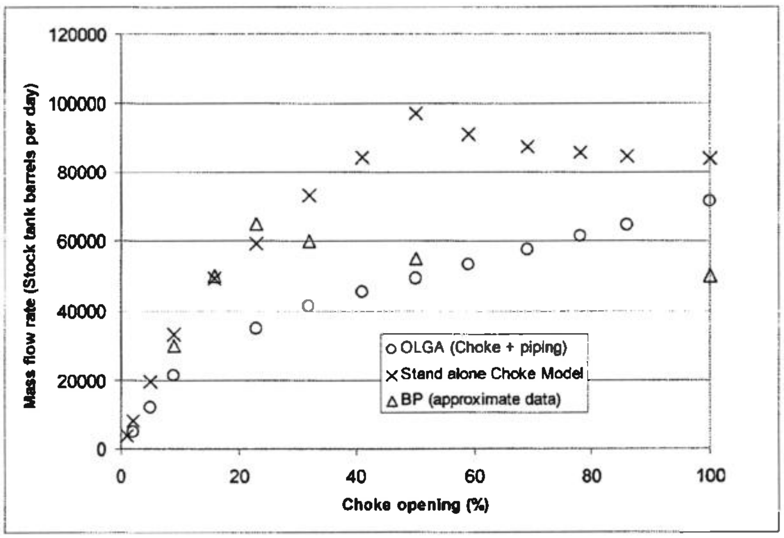
Comment [SSO2]: ???

A diagram showing flow rate as a function of choke opening is attached. The calculations for the stand alone choke model do not include frictional pressure drops in the piping systems, so these flow rates are over predicted. The choke model predicts sub-critical flow at all operating points. The model is a frozen flow model, so no flashing occurs in the valve.

Comment [SSO3]: Stemmer dette?

Comment [SSO4]: Dette gjelder bare mellom innløp og kritisk tverrsnitt. Men modellen tillater flashing i kontrollvolumet nedstrøms kritiskm tverrsnitt.

The piping system and choke have also been modelled with the flow simulator OLGA (http://www.sptgroup.com). This multiphase flow calculation program can predict flow rate for specified upstream and downstream pressure. A version of the Hydro Choke Model is implemented in OLGA. The PVTSim-file has been used to generate a fluid property table for the OLGA calculations. The results from the OLGA calculations are also included in the diagram below.



Comments:

The choke opening limits the flow rate for small openings and small flow rates where most of the pressure drop is across the choke. All the models seem to predict the same in this region.

When the chokes opens more than approximately 10%, it seems like the pressure drops in the piping and across the gasket become significant, and the OLGA model predicts lower mass flow rates than the stand alone choke model.

Comment [SS05]: ??

~~We believe that the OLGA predictions give a fair estimate of the operating conditions and response to changes in choke settings.~~

Comment [SS06]: Uenig. OLGA viser at choken kontrollerer flowraten for alle ventilåpninger. Da burde kurven for OLGA vært flat for ventilåpninger over ca 70%, og det er den jo ikke.

Comment [SS07]: Hvis OLGA er kjørt med 150 bara nedstrøms, ville jeg ikke tatt disse resultatene med!

The choke opening limits the flow rate for small openings and small flow rates where most of the pressure drop is across the choke. The choke will operate critically if the pressure drop is large enough.

The pressure drop across the upstream restriction, having a flow area of 42% of the maximum choke opening, will be large when the choke opens, and the flow may become critical at this location.

The gas expansion (and flashing of gas from the oil phase) and friction effects may result in choked flow at the pipe exit (Fanno flow) limiting the flow rate through the system.

In addition there are frictional pressure drops in the piping that affect the pressure distribution.

We believe the assumption of downstream pressure of 150.9 bara (2189 psia) is the origin of the strange and unphysical results.
1) In a pipe system like this may the phenomenon multiple choking occurs, i.e. the flow will be critical in more than one cross-section of the pipe system. The critical cross-section furthest downstream will determine the mass flow rate. Upstream there may be both subsonic and supersonic flow as well as shocks. A model of this has to allow implicit solution of multiple choking for complex pipe geometries.
2) If there not is sufficient flow restrictions and friction to dissipate enough stagnation pressure upstream, the flow will choke where the pipe exits into the sea. The mass flow rate will be determined here. The exit pressure will be larger (or equal) the sea pressure, and there will be further expansion and dissipation in the form of normal or oblique shocks etc in a turbulent jet to thesea.

It should be possible to develop a model combining the Hydro choke model with pipe flow as described above, but we do not have that available now. It would be useful to have a tool that could determine how these high velocities compressible flows behave in complex piping systems. The basis for such a model was developed by DNV and partners in the mid 90ies for one and two component flows based on a similar model as the HYDRO-model. However, the model would have to be made operational again and further validated. This wasdone within the framework of a French, Belgian, German, Polish and Norwegian collaborative R&D project with financial support from the EC, CEA, UCL, TUHH, DNV, Statoil, ConocoPhillips, ++.

We hope the above information gives you some ideas of how to proceed finding a good prediction model for your system.

Best regards,
Reidar