Natalie Eades

From:	Reidar B. Schuller
Sent:	Wednesday, August 25, 2010 2:14 PM
To:	Miller, Wayne O.
Cc:	Ruben Schulkes; Stale.Selmer-Olsen@dnv.com
Subject:	Hydro choke model
Attachments:	Flow rate predictions.jpg

Dear Wayne

I am sorry for the delay in giving you some answers to your questions, but below you will find some results from calculations and some comments to the complexity of the flow problem.

The information from the choke manufacturer shows 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 are 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 must become less sensitive to changes in choke opening when the opening is 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.
- 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%.

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, especially at larger choke openings.

The choke model predicts sub-critical flow at all operating points, mainly because there is much liquid when the upstream pressure is high. The model is a frozen flow model, so no flashing occurs from the inlet to the minimum cross section at the vena contracta.

Comments:

The maximum gas mass fraction in the present case is approximately 24% giving gas volume fractions between 50 and 60%, and the choke model did not predict critical flow for any of the valve openings. For situations with higher gas fractions the flow may readily become choked if the pressure drop is high.

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 may 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 including some 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, so this is a complex flow problem where it is difficult to determine what actually determines the flow rate.

We also believe that the assumption of a downstream pressure of 150.9 bara (2189 psia) may be uncertain, especially for flows with large gas fractions.

1) In a pipe system like this the phenomenon multiple choking may occur, i.e. the flow may 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.

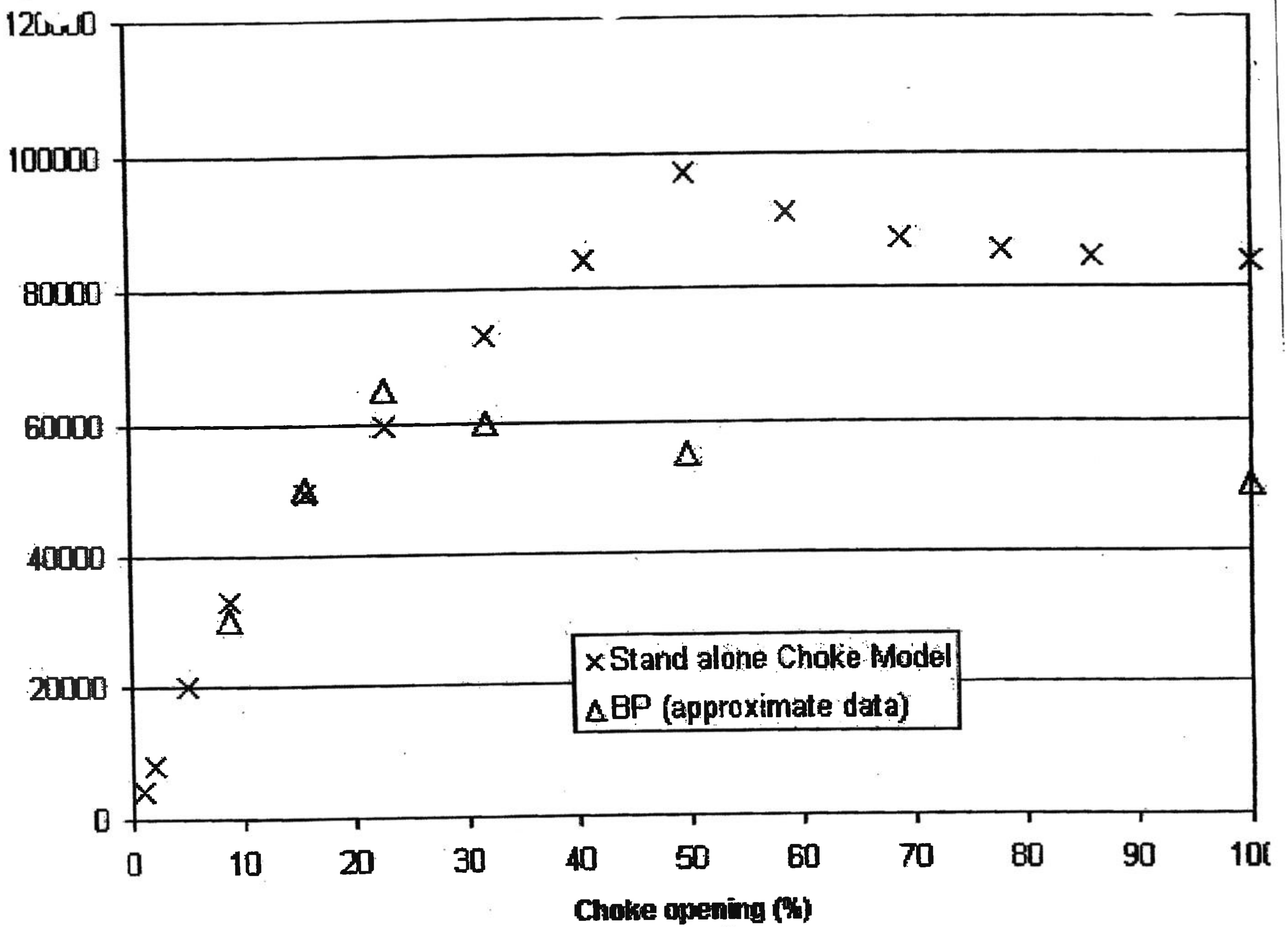
2) If there not is sufficient flow restrictions and friction to dissipate enough stagnation pressure upstream, the flow will choke where the pipe exits into the sea. The mass flow rate will be determined here. The exit pressure will be larger (or equal to) the sea pressure, and there will be further expansion and dissipation in the form of normal or oblique shocks etc in a turbulent jet to the sea.

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 velocity 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 was done 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 on how to proceed finding a good prediction model for your system.

Best regards,

Reidar


120000
100000
80000
60000
40000
20000
0
0
10
20
30
40
50
60
70
80
90
100
Choke opening (%)
Stand alone Choke Model
BP (approximate data)