Statoil

Note

2010-09-21

To	Ruben Schulkes Geir Elseth
Copy	
From	R B Schüller
Case	**Choke calculations - GOM Incident**

1 Summary

Statoil was in July 2010 contacted by Wayne Miller in Lawrence Livermore National Laboratories (LLNL) via Ståle Selmer-Olsen in Det norsk Veritas in relation to BP's oil leakage in the GOM. Contact was made with Ruben Schulkes in Statoil. Reidar Schüller was asked to carry out the calculations with the Hydro Choke Model.

LLNL had tried to make a flow model of the 4" choke valve that managed to close in the leaking well, but they were not convinced that their model was correct. Statoil was therefore asked to see how the Hydro Choke Model[1 2], calculated the flow through the choke. Input from LLNL is found in separate pdf-document attached to the end of this note.

The geometry of the flowing system consisted of pieces of 3" piping connected both upstream and downstream of the 4" valve. A gasket upstream of the choke valve also reduced the cross sectional areas to 42% of the maximum choke area. The 3" piping is 60% of the maximum choke opening.

LLNL supplied a PVTSim file that described the wellfluid. PVTSim was used to generate a three phase fluid property input table to be used with the Hydro Choke Model. (The same property file was also used in the OLGA calculations that were performed.)

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[1] Schüller, R.B., T. Solbakken, and S. Selmer-Olsen, (2003), "Evaluation of Multiphase Flow Rate Models for Chokes Under Subcritical Oil/Gas/Water Conditions", *SPE Production and Facilities*, 18(3): p. 170-181.

[2] Schüller, R.B., J.S. Munaweera, S. Selmer-Olsen, and T. Solbakken, (2006), "Critical and Sub-Critical Oil/Gas/Water Mass Flow Rate Predictions for Chokes", *SPE Production and Operations*, 21(3): p. 372-380.

Calculation were first made with a stand alone version of the Hydro Choke Model where the maximum effective choke opening was limited to 50% as a result of the restrictions in the flow lines. This model did not include losses in the pipes or in the gasket and therefore over predicts the flow rate.

The gas mass fraction at inlet varied from zero to 24% giving gas volume fractions as high as 50-60%. The flow geometry was modelled in Fluent for compressible single phase gas flow to see which geometrical factors that governed the flow rate in the extreme case with choked flows. The results showed that the choke valve was only one important factor. The flow could choke in the gasket, and the flow also choked at exit from the piping system.

It was therefore decided to model the piping with gasket and choke valve in OLGA. These calculations were successful, but OLGA considers the flow regime to be stratified in the pipes. This is doubtful since the flow at large openings have high velocities and severe gas/liquid mixing is taking place in bends, gasket area and in the choke.
A number of calculations were made with OLGA 6.2 where the geometry was represented as a straight flow path (no bends), but with the correct changes in pipe diameters. The choke was modelled with the version of the Hydro choke model implemented in OLGA.

A pressure plot for different choke openings is shown in Figure 10 and a gas velocity plot in Figure 11. A plot including mass flow rate from the OLGA calculations is shown in Figure 1.

The results from the OLGA calculations show that the effect of changing choke opening is large, also when the opening is larger than 60%. This is probably not correct since the upstream and downstream pipe cross sectional areas are 60% of the maximum choke opening area. A calculation removing the choke completely gave a much larger flow rate. (See diagram.) It was therefore decided not to send the OLGA results to LLNL.

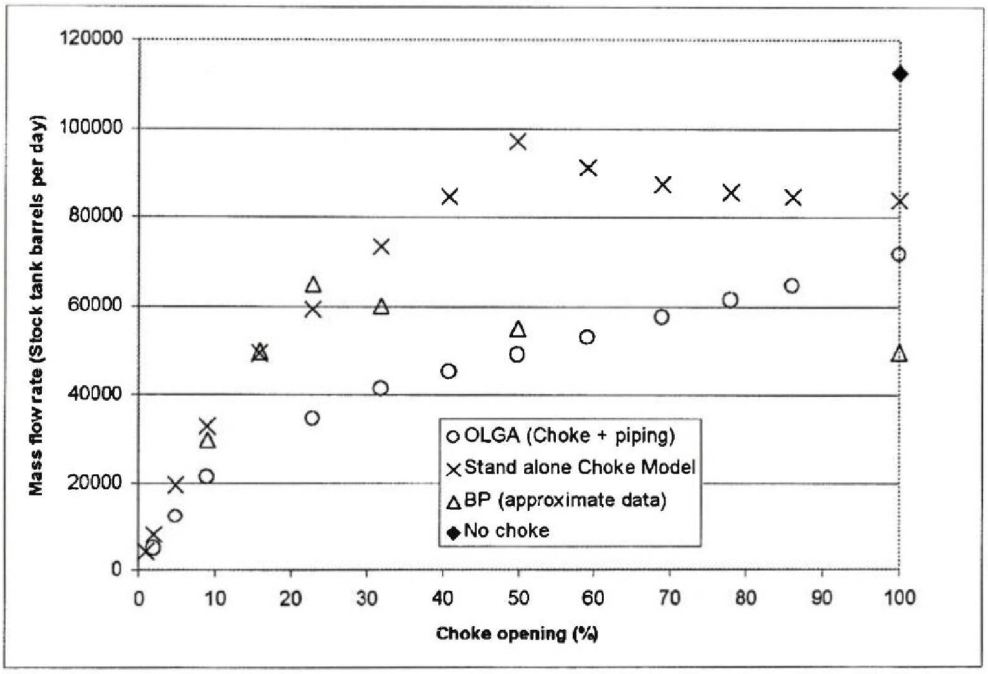


Figure 1: Mass flow predictions from different models

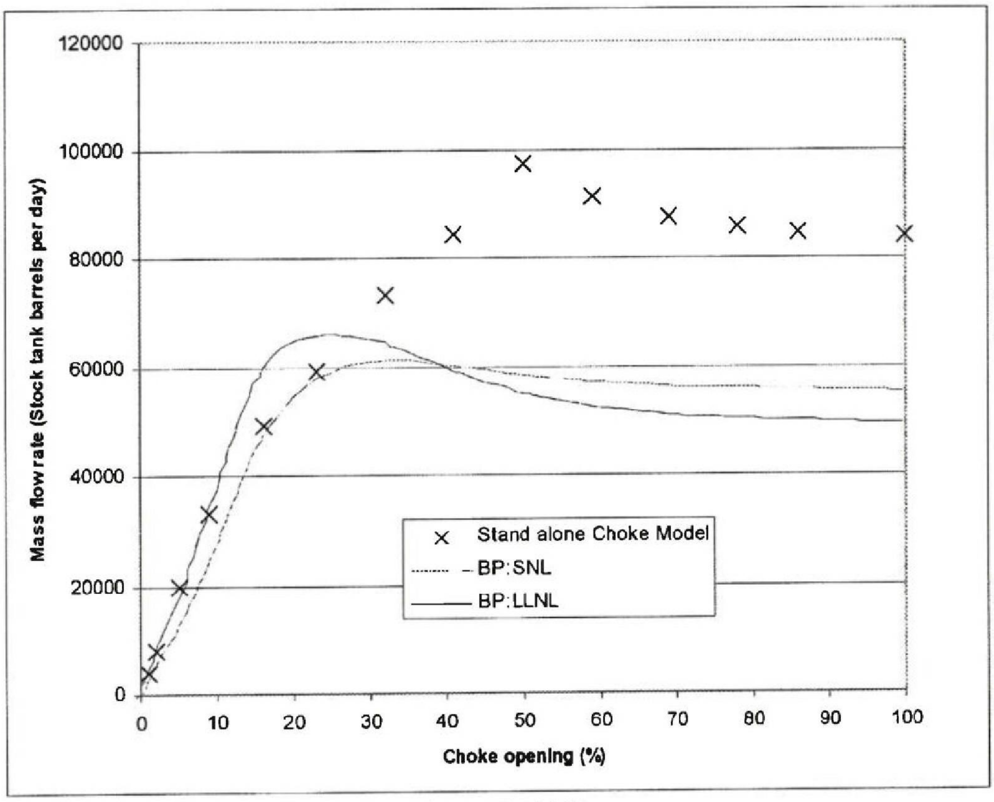


Figure 2: Comparison with prediction models used by LLNL.

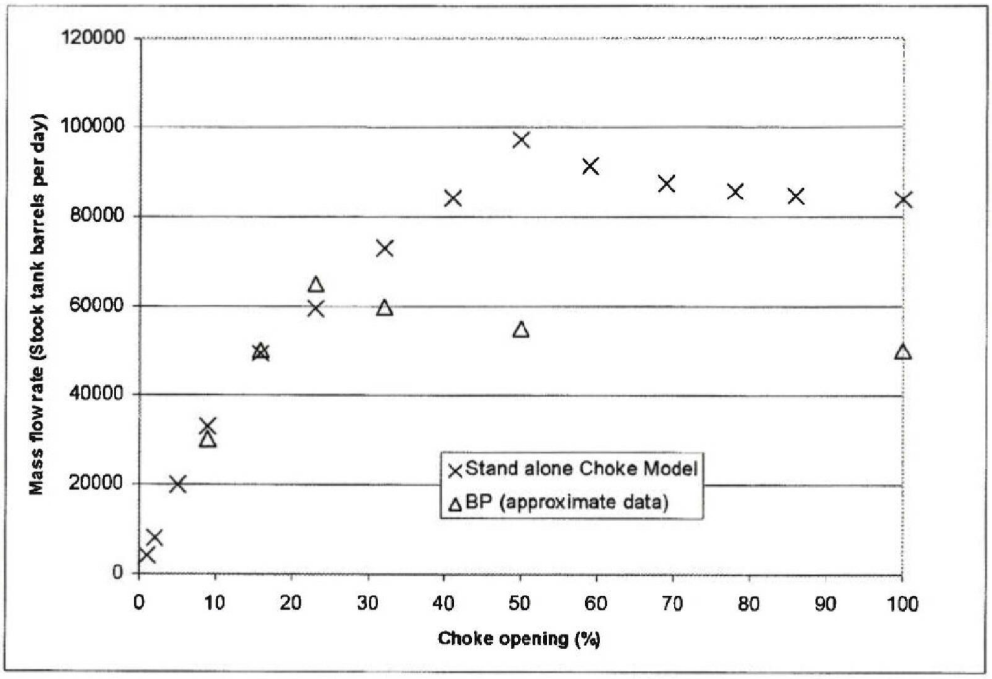


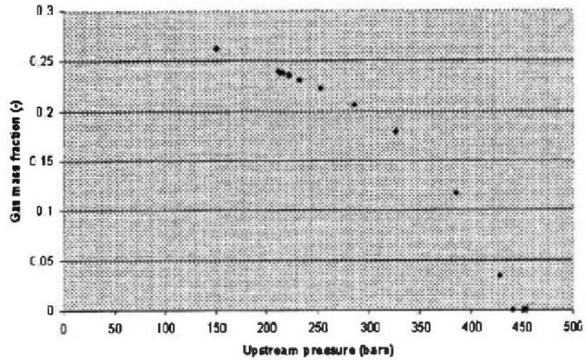
Figure 3: Diagram sent to LLNL.

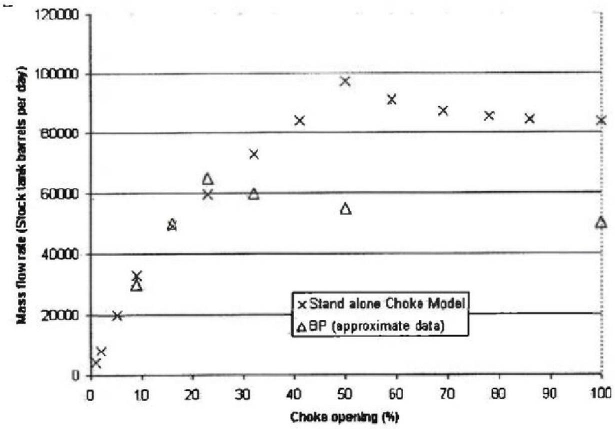
2 Answer given to LLNL

The following email was sent to Wayne Miller:

From: Reidar B. Schuller [mailto:rbsc@statoil.com]
Sent: Wednesday, August 25, 2010 12:14 PM
To: Miller, Wayne O.
Cc: Ruben Schulkes; Stale.Selmer-Olsen@dnv.com
Subject: Hydro choke model

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.





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.

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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

Appendix A: Results from Fluent calculations

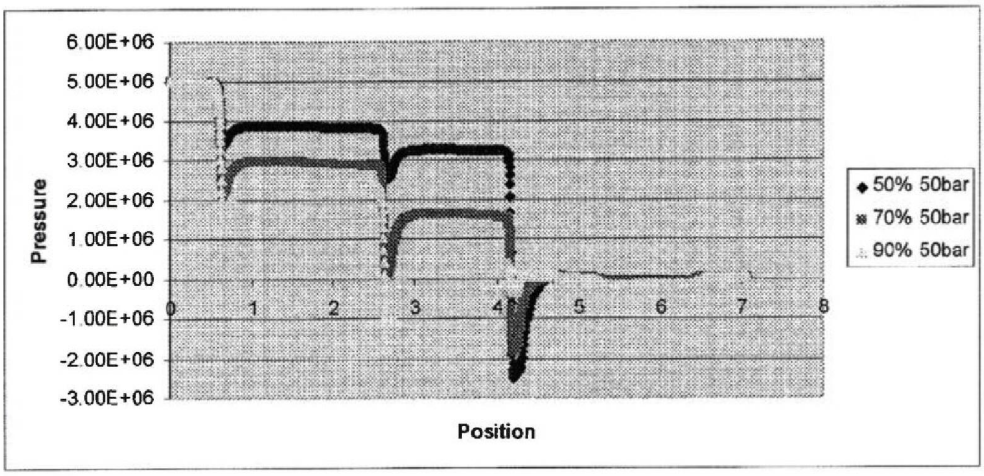

Figure 4: Pressure profile. Notice small dp over choke at 90% opening

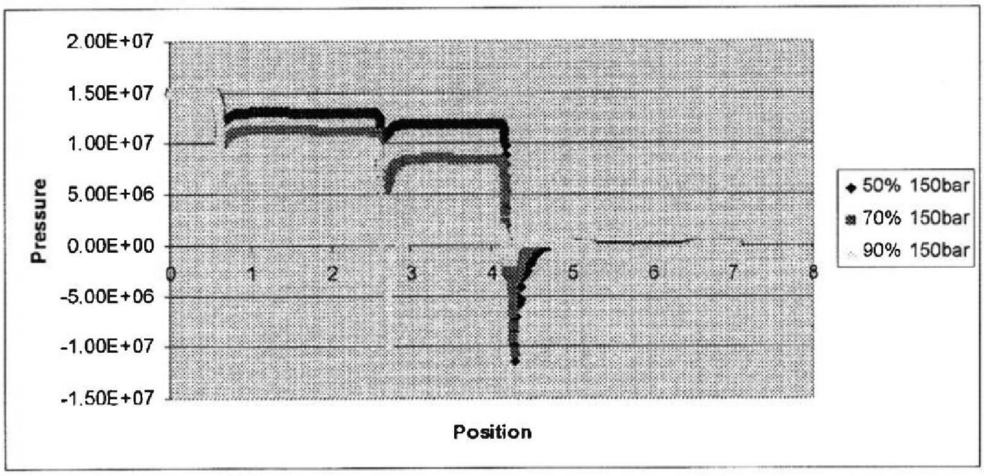

Figure 5: Pressure profile

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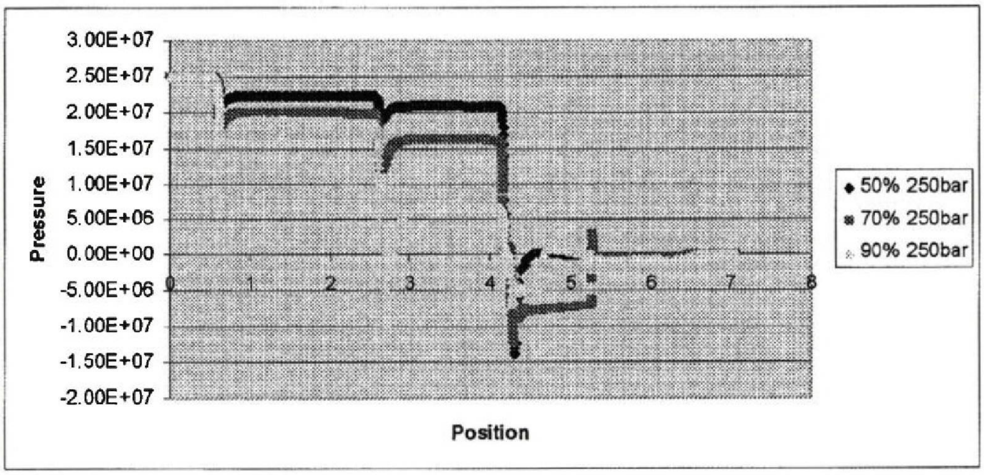

Figure 6: Pressure profile

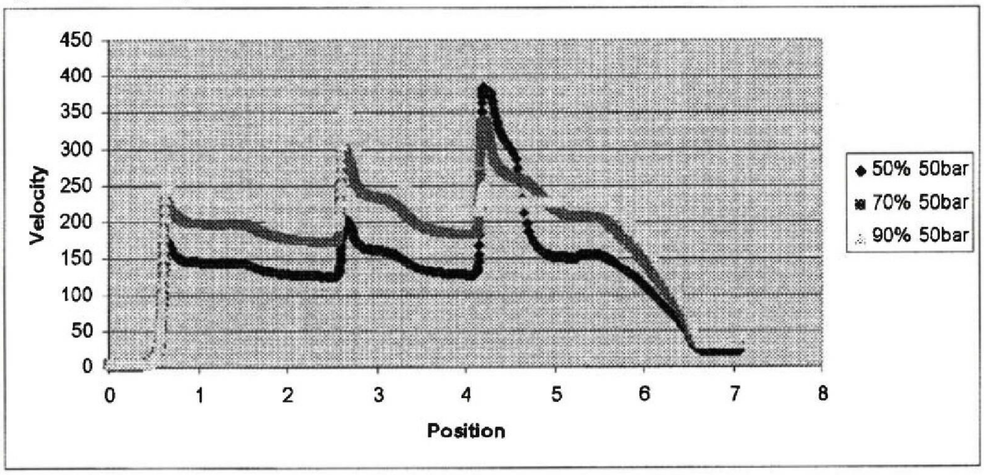

Figure 7: Velocity profile

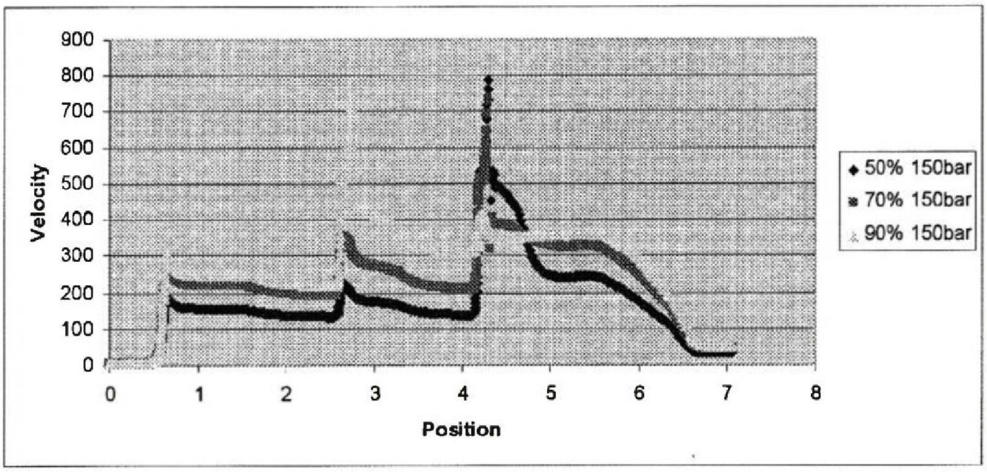

Figure 8: Velocity profile

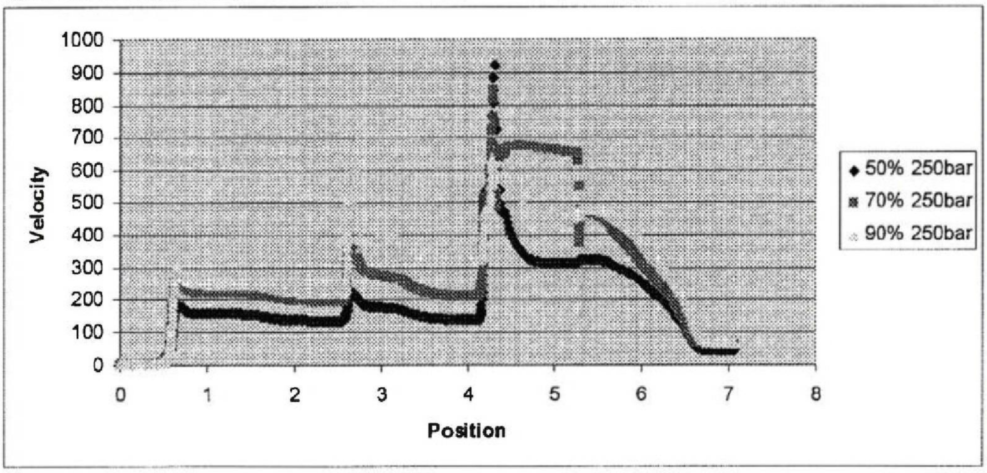

Figure 9: Velocity profile. Notice choked flow at pipe exit at 70% opening.

3 Appendix B: Results from OLGA calculations

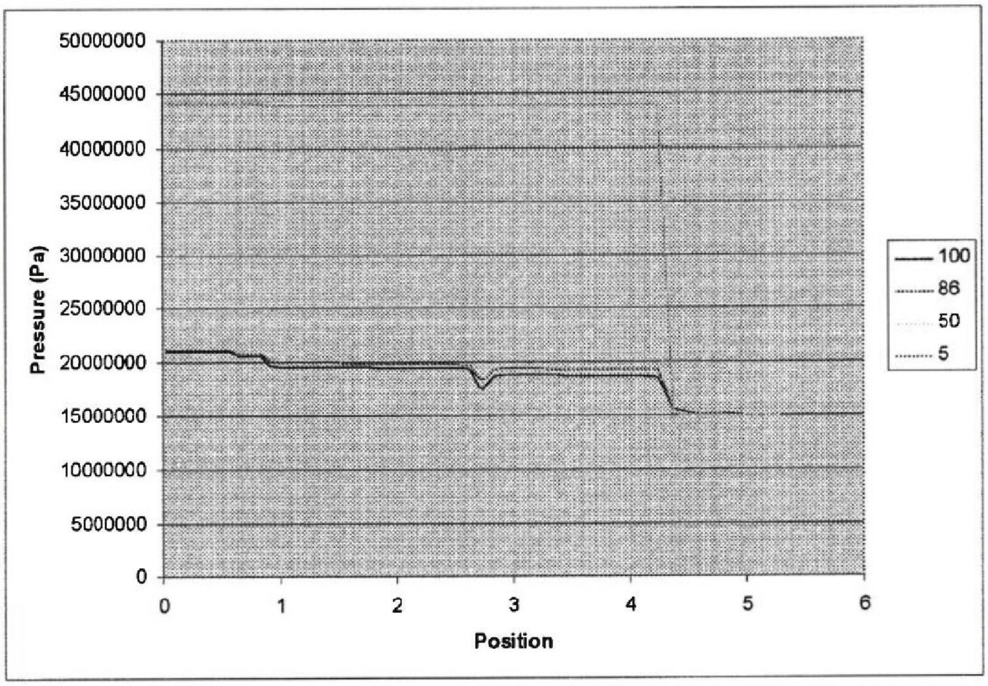

Figure 10: Pressure profiles for different choke openings. Maximum pressure drop is across choke.

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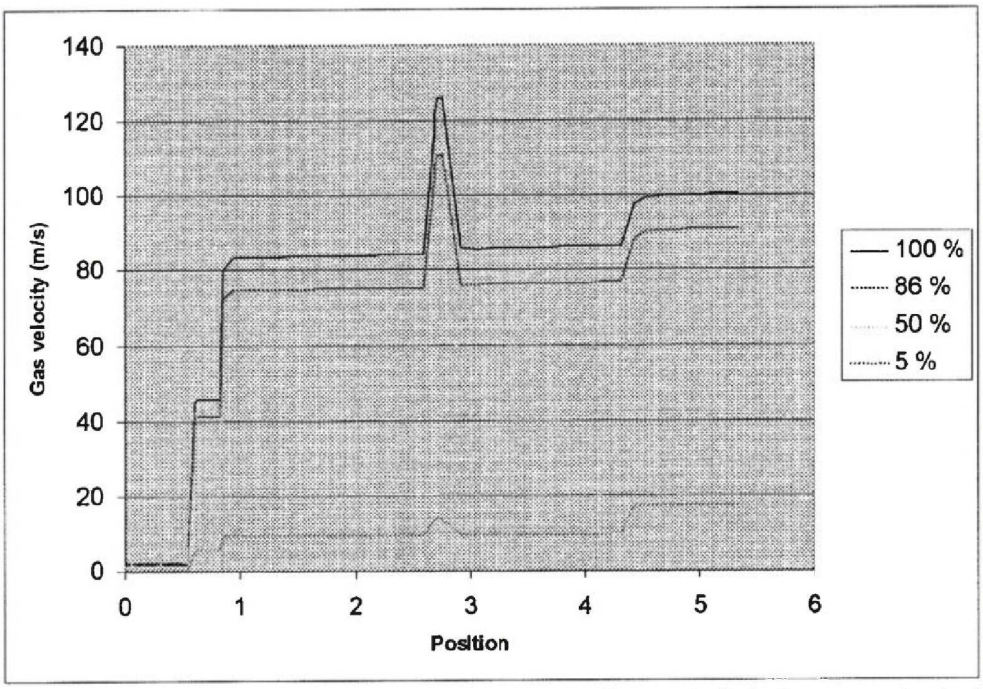

Figure 11: Gas velocity for different choke openings. The maximum velocity in the vena contracta of the choke is not shown in the diagram.

INFORMATION RECEIVED FROM LLNL (W. Miller, email dated 06.08.2010) is attached on the following pages.

Notes for Statoil Analysis of CC40 Choke Valve (1)

- First, thank you!   Contact me with any needs or questions: Wayne Miller, miller99@llnl.gov

- You should have the following documents:
  - Notes for Statoil.ppt (this presentation)
  - Preliminary_EOS.fdb - PVT.sim file
  - CC40 Choke Valve Notes.pdf – comments on choke valve geometry
  - CC40 Section.pdf – section view of choke valve

- Choke valve is a Cameron CC40 plug & cage type
  - http://www.coopercameron.com/content/products/product_detail.cfm?pid=2862&bunit=dps

Notes for Statoil Analysis of CC40 Choke Valve (2)

- The intent of this analysis is to predict the flow through the CC40 during the July 15 well integrity test. The well integrity test was used to stop all flow in the capped well using the CC40 as the only line out of the well.
- The test proceeded in discrete steps over several hours as the valve was closed by ½ turn for each step until the valve was completely closed.
- At each step in the test, the pressure upstream of the valve was recorded (see following table). The pressure measurements were taken in an 18" diameter vertical pipe, before the oil was forced into the 3" diameter choke line (see following schematic). Consequently there are additional pressure drops between the pressure gauge and the valve inlet due to viscous loss and gravity head.
- The choke valve exhausts to the open ocean through a short exhaust pipe. The ocean pressure at the exit was 2189 psia.

Notes for Statoil Analysis of CC40 Choke Valve (3)

- Flow models created by the U.S.A. flow analysis teams used 1-D pipe flow methods, with head loss “K” factors to account for the valve restriction, and also for pipe fittings (bends, expansions, etc.).

- We used a standard correlation relating valve Cv to K, expressed as
  - $K = 29.9^2 * D^4/Cv^2$ D is valve diameter, Cv has traditional units of gallons/minute/(psi)$^{0.5}$

- The models created by the U.S.A. flow analysis team all showed a non-physical increase in flow rate as the valve was closed (see following figure), when using the measured upstream pressure. The models agreed well with straight-through (no choke valve) results. We suspect the complex 2-phase behavior in the valve during closure is missing from our models. We hope your HYDRO model will capture this.

Notes for Statoil Analysis of CC40 Choke Valve (4)

- Requested Results from Statoil
  - Develop a HYDRO analysis model of the choke valve and the choke line plumbing
  - Duplicate the well integrity test by ½ turn steps using the upstream gauge pressures given in the following table and the constant ocean exhaust pressure.
  - Send me your results of flow rate for each step in the test in a table
  - Please add your own comments on the flow behavior as you observe it. Does it choke (sonic)? Do multiple species flash in the valve?

- Note: The hydrocarbon flow has about 2900 standard cubic feet of methane per stock tank barrel of oil. The bubble point is about 6600 psia. There is no water. I have been using the following conversion to get stock tank barrels per day:

  1 kg/s of total mass flow = 485 stock tank barrels per day

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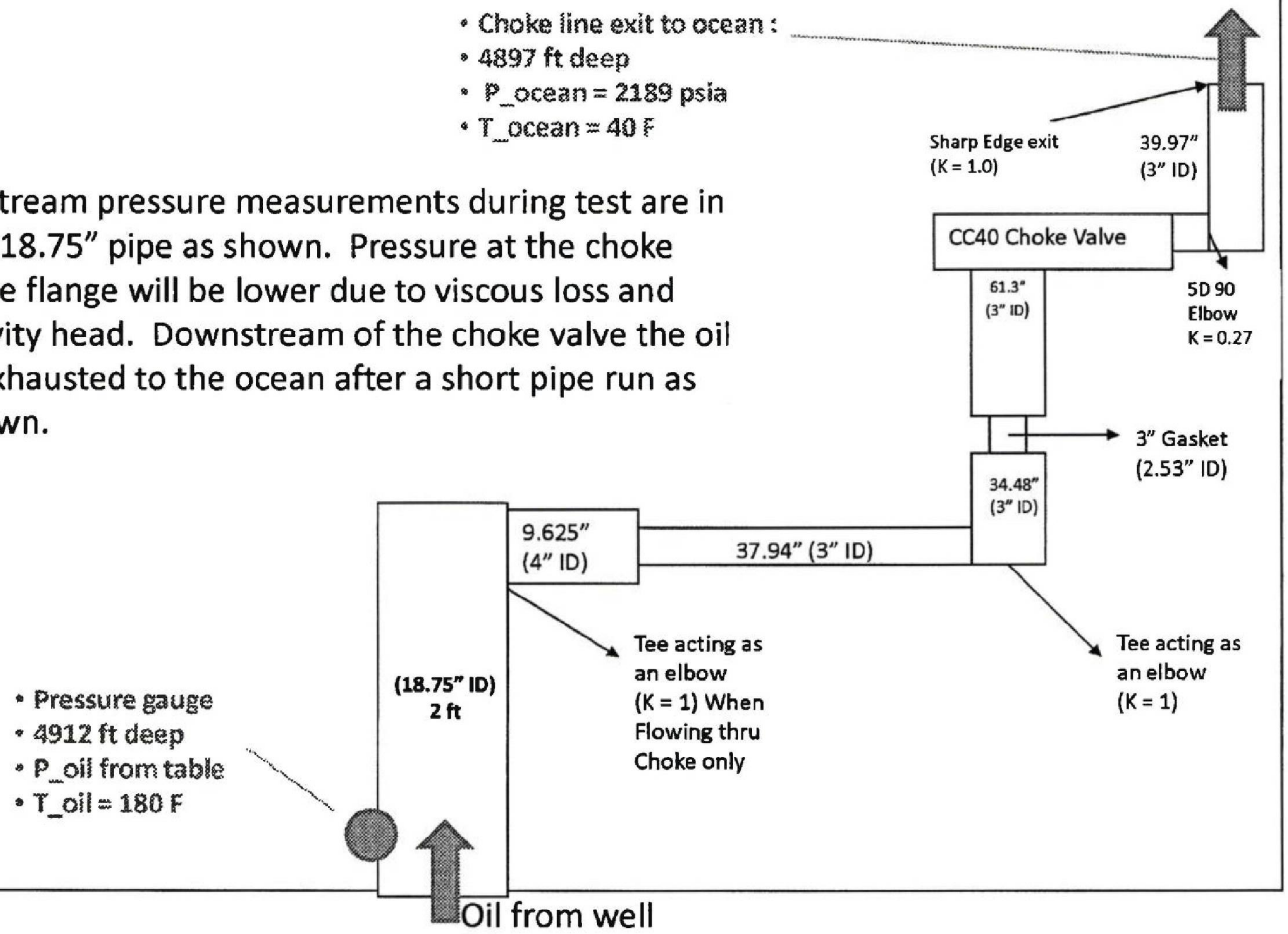
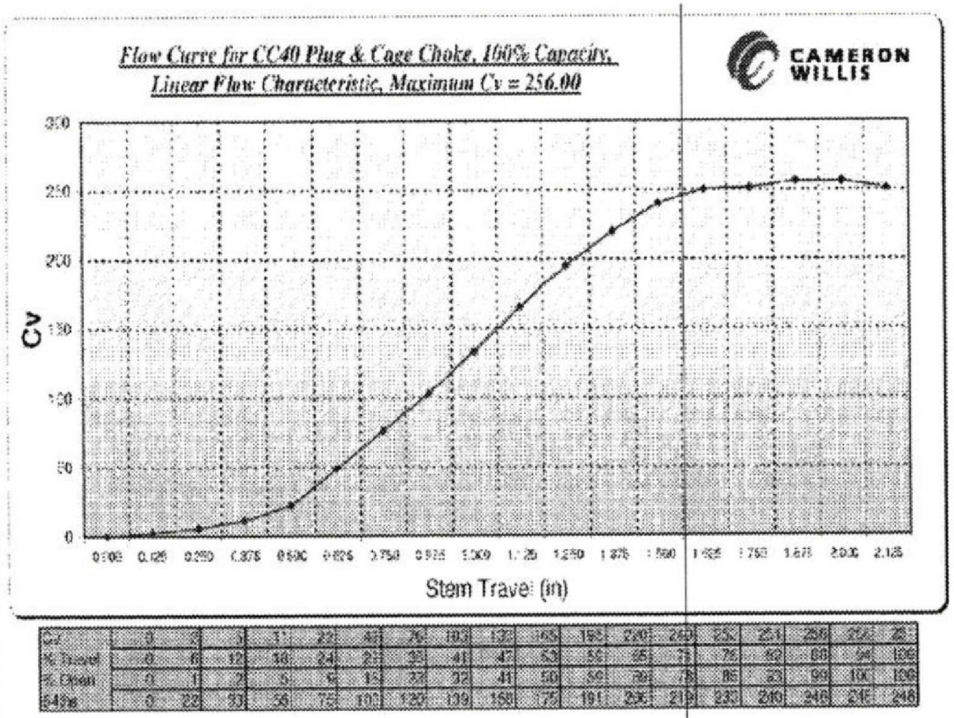
Choke Line Schematic

Upstream pressure measurements during test are in the 18.75" pipe as shown. Pressure at the choke valve flange will be lower due to viscous loss and gravity head. Downstream of the choke valve the oil is exhausted to the ocean after a short pipe run as shown.

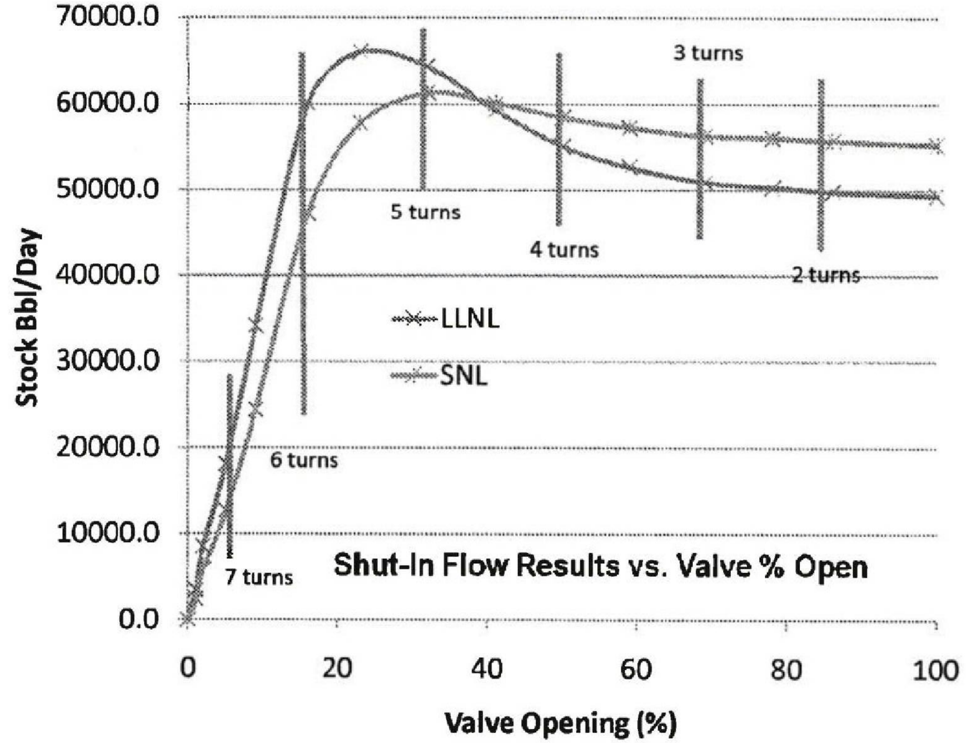


CC40 Choke valve characteristics and choke pressure data for July 15 well integrity shut-in test

# Turns	P_gauge	% Open	Cv
0	3051	100	251
2	3065	86	250
2.5	3089	78	240
3	3130	69	220
3.5	3220	59	195
4	3374	50	165
4.5	3662	41	133
5	4139	32	103
5.5	4738	23	76
6	5592	16	49
6.5	6210	9	22
7	6398	5	11
7.5	6538	2	5
8	6568	1	2
8.5	6595	0	0



Our choke line models show nonphysical flow increase as valve is closed



- **Uncertainties with Choke Calculation**
  - Multiphase Flow effects -- Cv and K values are based on water. Multiphase flow is more complicated and may yield higher K values (which yields a lower predicted flow)
  - Model is a series of steady state conditions, but data never achieves steady state flow in the well.

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Wayne,

Please find attached document which shows a cross section of the choke and identifies the key components that control the flow through the choke. The key dimensions are:

- The plug outside diameter and cage inside diameter are nominally 3-7/8"
- The plug has a 30 degree chamfer (3/16" long) on the leading edge of it.
- The seat inside diameter is 3-5/8"
- There are 2 zones of circular ports in the inner cage
- The first zone has 6 X ∏" holes and these are centred 0.38" from the seated position – i.e these holes would be 50% exposed when the plug has moved 0.38" from the fully closed position.
- The second zone has 6 X 1∏" holes and these are centred 1.19" from the seated position.
- 8.5 turns of the choke over-ride corresponds to 2-1/8" movement of the plug.

This should allow you to model the choking elements (orifice restriction) of the choke.

Regards
Stephen

Stephen,

During shut-in as the choke valve was being closed, the back pressure rose in the well head, as you would expect. However, our calculations of flow through the choke valve showed flow increasing gradually from turn 0 to turn 5 by about 10%, before it started to drop and head toward zero flow at 8.5 turns (fully closed). This increasing flow behavior is puzzling to us and we were wondering if it meant that the Cv we are using should maybe be adjusted slightly for the 2-phase oil and gas flow. That is why we were asking if there were any experimental data for the CC40 with oil+gas flow.

What do you think?

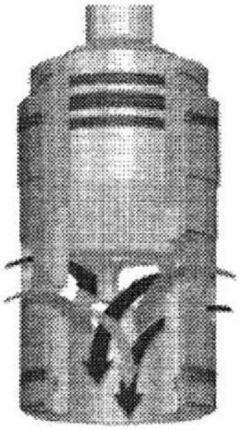
Thanks for your time Stephen.
Curtt

At 09:27 AM 7/27/2010, Chambers, Stephen wrote:

Curt,

Cv is a measure of valve capacity and is independent of the fluid passing through the choke. Cv testing is generally performed using water, but the Cv obtained can then be used in the formulae for gas or liquid flow.

In relation to the question in the original email below, I presume you are asking with reference to the attached curve why the Cv is 256 at 94% travel and then drops by approx 2% to 251 at 100% travel. This is something that we often see on Cv curves. The Cv on this type of choke is adjusted by moving a plug up and down within a ported cage (ref image below).

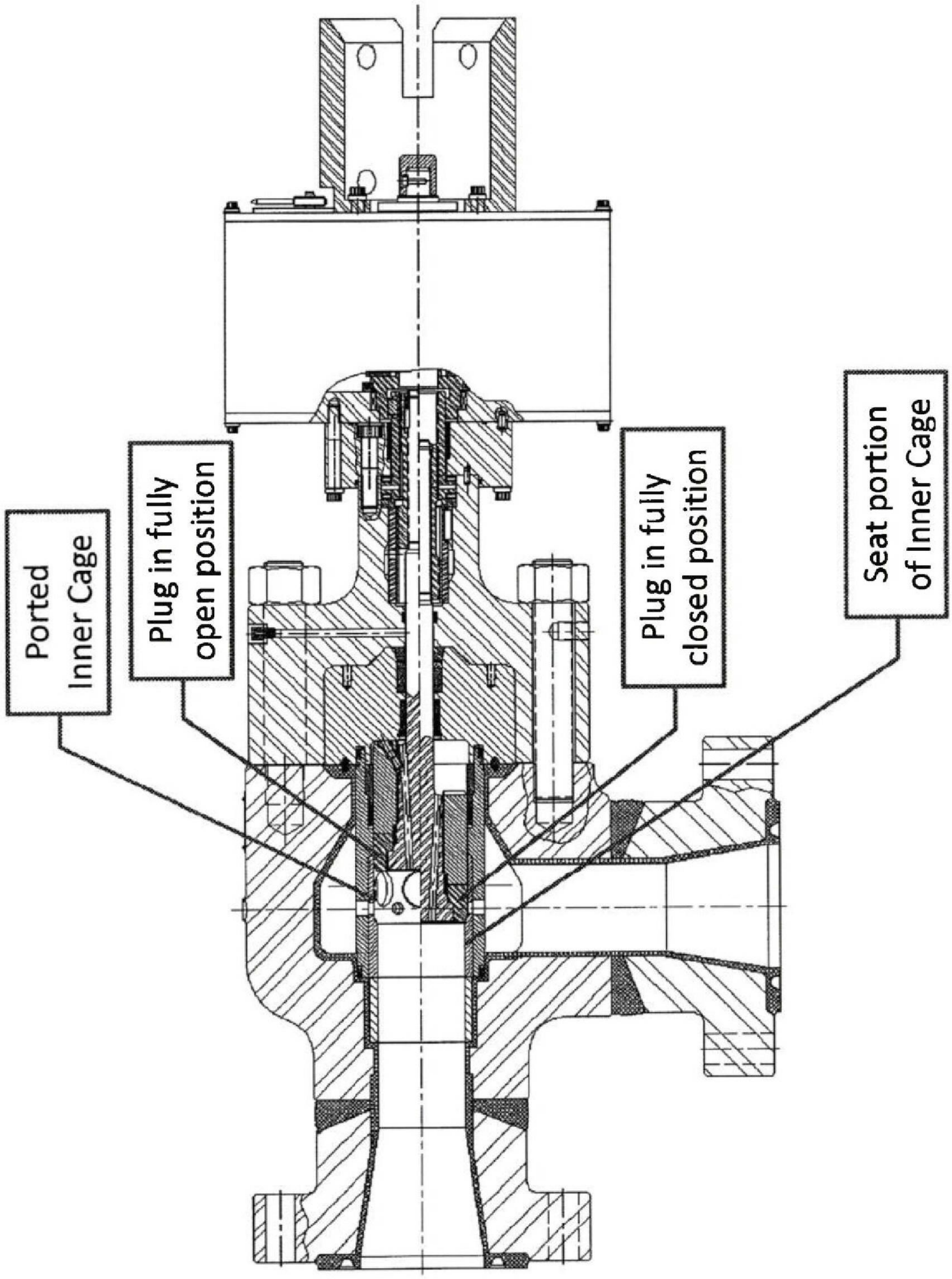


At the point where the maximum Cv is achieved, the ports in the side of the cage will be already fully exposed. You find however that as the plug is opened further, it generates some additional recirculation between the uppermost ports and the bottom of the plug that has the effect of impeding the flow and results in a reduction of Cv.

Hopefully this answers your questions.
Best Regards

Stephen Chambers
Product Engineering Manager
Flow Control

Cameron Ireland Ltd
Aghafad
Longford
Ireland
Tel 353.43.3350631
Fax 353.43.3341560
<mailto:Stephen.Chambers@c-a-m.com>Stephen.Chambers@c-a-m.com


Ported
Inner Cage
Plug in fully
open position
Plug in fully
closed position
Seat portion
of Inner Cage

MUTUAL NONDISCLOSURE AGREEMENT FOR EXCHANGE OF INFORMATION WITH LAWRENCE LIVERMORE NATIONAL LABORATORY

This Agreement, effective on the date the last party signs, is made by and between STATOIL ASA located at Forusbeen 50, 4035 Stavanger, Norway, and LAWRENCE LIVERMORE NATIONAL SECURITY, LLC, (LLNS), under its Contract No. DE-AC52-07NA27344 with the U.S. DEPARTMENT OF ENERGY ("DOE"), as operator of the LAWRENCE LIVERMORE NATIONAL LABORATORY ("LLNL"), located at 7000 East Avenue, Livermore, CA 94550.

WHEREAS LLNS, as operator of LLNL, and STATOIL (hereinafter individually referred to as the "PARTY" or collectively as the "PARTIES") wish to exchange certain confidential and proprietary information relating to LLNL's oil properties and plumbing details on the undersea well leak and STATOIL's results on oil flow rate estimates through a choke valve predicted by their HYDRO model ("PROPRIETARY INFORMATION"), this Agreement will govern the conditions of mutual disclosure of PROPRIETARY INFORMATION by the PARTIES.

The PARTIES hereby agree:

(1) To perform all terms of this Agreement and to maintain the PROPRIETARY INFORMATION in confidence, giving it the same degree of care, but no less than a reasonable degree of care, as the receiving PARTY exercises with its own proprietary information to prevent its unauthorized disclosure.

(2) To exchange and use the PROPRIETARY INFORMATION solely for the purpose of evaluation, testing, and development of potential collaborations, joint ventures, and/or license of the technology.

(3) That neither PARTY, without the prior written consent of the other, will disclose any portion of the PROPRIETARY INFORMATION to others except to their employees, agents, consultants, subcontractors or Government personnel having a need to know in order to accomplish the sole purpose stated above, and who are bound by a like obligation of confidentiality under this Agreement.

(4) Receiving PARTY may disclose PROPRIETARY INFORMATION without the other PARTY's written consent only to the extent:
  (a) the receiving PARTY can demonstrate by written record was previously known to them;
  (b) is, or becomes, available to the public through no fault of the receiving PARTY,
  (c) is lawfully obtained by the receiving PARTY from a third party and is not subject to an obligation of confidentiality owed to the third party, or
  (d) is independently developed by or for the receiving PARTY independent of any disclosure hereunder
  (e) such disclosure is required to be disclosed under applicable law, stock exchange regulations, court order, or by a governmental order, decree, regulation or rule (provided that the receiving Party shall make all reasonable efforts to give prompt written notice to the disclosing Party prior to such disclosure)

(5) That PROPRIETARY INFORMATION disclosed by the PARTIES will be in writing and clearly marked "PROPRIETARY INFORMATION" or its equivalent. If such PROPRIETARY INFORMATION is initially disclosed orally or by demonstration, it will be identified as PROPRIETARY INFORMATION or its equivalent at the time of disclosure. The disclosing PARTY will, within thirty (30) days thereafter: (a) reduce such PROPRIETARY INFORMATION to writing or other tangible form, referencing the date and type of PROPRIETARY INFORMATION disclosed, and mark it as PROPRIETARY INFORMATION or its equivalent, and (b) deliver a copy to the receiving PARTY. All protections and restrictions as to use and disclosure will apply during such thirty (30) day period.

(6) That all rights and title to the PROPRIETARY INFORMATION disclosed under this Agreement will remain the property of disclosing PARTY unless otherwise agreed to in writing by the PARTIES.

(7) That PROPRIETARY INFORMATION provided by any disclosing PARTY to any receiving PARTY shall be returned to the disclosing PARTY within five (5) days of written request for such return by the disclosing PARTY.

(8) That no copies shall be made by a receiving PARTY of any PROPRIETARY INFORMATION without the express written consent of the disclosing PARTY. Any copies so authorized shall be returned to the disclosing PARTY or destroyed in accordance with the term and demand provisions of this Agreement.

(9) The PARTIES agree that any photocopy or facsimile copy of this fully-executed Agreement shall have the same legal force and effect as any copy bearing original signatures of the PARTIES.

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(10) THE PROPRIETARY INFORMATION, , ARE PROVIDED "AS IS" WITH ALL FAULTS, WITHOUT ANY EXPRESS OR IMPLIED WARRANTIES OF ANY TYPE WHATSOEVER, INCLUDING BUT NOT LIMITED TO IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUALITY, ACCURACY, COMPLETENESS, TITLE OR NON-INFRINGEMENT. EACH PARTY SHALL ASSUME IT'S OWN RISK ASSOCIATED WITH THE PROPRIETARY INFORMATION, SUCH AS RISKS ASSOCIATED WITH QUALITY, PERFORMANCE, DATA LOSS AND WITH THE EXPLICIT UNDERSTANDING AND AGREEMENT THAT THE DISCLOSING PARTY, ITS AFFILIATED COMPANY, AGENTS, CONSULTANTS, AND OFFICERS, DIRECTORS AND EMPLOYEES OF THE AFOREMENTIONED ENTITIES SHALL HAVE NO LIABILITY WHATSOEVER WITH RESPECT TO USE OR RELIANCE UPON THE CONFIDENTIAL INFORMATION, INCLUDING BUT NOT LIMITED TO ANY ACTIONS OR NON-ACTIONS A PARTY MAY TAKE OR NOT TAKE BASED ON THE PROPRIETARY INFORMATION RECEIVED SHALL BE AT THE PARTY'S OWN RISK AND RESPONSIBILITY AND SUCH PARTY SHALL HAVE NO CLAIM AGAINST THE DISCLOSING PARTY AS A CONSEQUENCE THEREOF.

(11) Technical Contact for Company:

Name: Ruben Schulkes
Company: STATOIL
Address: Forusbeen 50
4035 Stavanger
Norway
Phone: 47 51 99 00 00 (main)
47 48 14 32 70 (direct)
Fax: 47 51 99 00 50 (main fax)
Email: rubs@statoil.com

Technical Contact for LLNL:

Name: Wayne Miller
Company: Lawrence Livermore National Laboratory
Address: 7000 East Avenue
L-140
Livermore, CA 94550
Phone: [redacted]
Email: Miller99@llnl.gov

(12) It is further agreed that the furnishing of PROPRIETARY INFORMATION does not constitute any grant or license to the other PARTY for any legal rights now or hereinafter held by either PARTY.

(13) Unless terminated earlier by thirty (30) days written notice by either PARTY to the other, this Agreement will remain in effect for two (2) years from the effective date, at which time the receiving PARTY will return or destroy the PROPRIETARY INFORMATION within thirty (30) days of the termination of this Agreement. If the PROPRIETARY INFORMATION is destroyed, a certificate of destruction must be furnished to the disclosing PARTY within the thirty (30) days. The secrecy and non-use obligations of the receiving PARTY set forth above will remain in effect for five (5) years from the effective date.

(14) The PARTIES shall make a diligent effort to settle amicably all disagreements in conjunction with this contract. If an amicable agreement is not reached all disputes arising out of or in connection with the present agreement shall be finally settled under the Rules of Arbitration of the International Chamber of Commerce by one or more arbitrators appointed in accordance with said Rules.

The receiving PARTY acknowledges its obligations to control access to technical data under the U.S. Export Laws and Regulations and agrees to adhere to such Laws and Regulations with regard to any technical data received under this Agreement.

(15) Any modification to this Agreement must be in writing and signed by the duly authorized representative of each PARTY.

LAWRENCE LIVERMORE NATIONAL SECURITY, LLC,
LAWRENCE LIVERMORE NATIONAL LABORATORY

Signature: [signature]

for Name: Erik Stenehjem
Title: Director, Industrial Partnerships Office

Date: 4 August 2010

STATOIL ASA

Signature: [signature]

Type Name: PER GUNNAR GRINI
Title: ~~Chief Researcher~~ ACTING DIRECTOR TNE-RD-RDS

Date: 4. August 2010

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