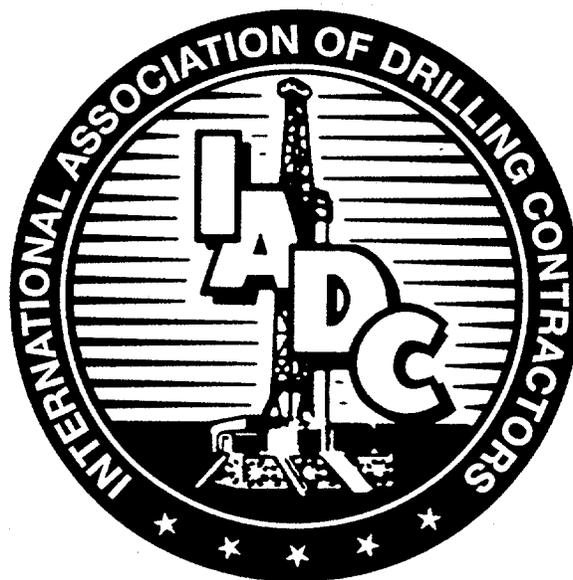


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...GLOBAL LEADERSHIP FOR THE DRILLING INDUSTRY...



**TRAINING CENTRE 'LEEUWENHORST'
IADC'S THIRD ANNUAL
EUROPEAN WELL CONTROL CONFERENCE**

JUNE 2, 3, 4, 1992
NOORDWIJKERHOUT
THE NETHERLANDS



Neddril

REGISTRATION FORM

Name(s) : _____

Company : _____

Telephone : _____ Fax: _____

Fee per person : IADC-members: US\$ 425.—
Non-members: US\$ 475.—

European members : Please invoice my company
 Payment in US\$ should be made to IADC account 355204029,
Rabo bank, Rheden, The Netherlands

US members: Send your cheque directly to IADC offices in Houston: IADC, P.O. Box 4287,
Houston, Texas 77210.

Hotel accommodation:

A limited number of rooms have been reserved at Training Centre "Leeuwenhorst"
until April 6, 1992 at a special discounted rate.

- Single room for two nights, including breakfast Dfl. 186
- Single room with bath for two nights, including breakfast Dfl. 231.55

Reservations made after April 6 will require payment of a surcharge.

For reservations and further details please contact Monique Kienhuis at IADC European Office,
Phone: ++31.85.645444 - Fax: ++31.85.630088

Conference registration:

Please return this conference registration form prior to May 20, 1992, to:

IADC
European Office
Attn: Monique Kienhuis
P.O. Box 13, 6880 AA Velp - The Netherlands
Telephone: 31-85-645444 - Fax: 31-85-630088

IADC UNIFYING A GLOBAL INDUSTRY BY BRINGING PEOPLE TOGETHER

Program Schedule

Tuesday June 2, 1992

19.00 - 21.00 Early registration at Training Centre "Leeuwenhorst"
Pre-Conference Cocktail Reception

Wednesday June 3, 1992

Location: Training Centre "Leeuwenhorst" Noordwijkerhout, The Netherlands

08.00 - 09.00 Registration

09.00 - 09.30 Opening of Conference Dr. Lee Hunt, President IADC
Piet Govers, Regional Vice President Europe, IADC

09.30 - 12.00 Morning Session: Well Control Training
Session Chairman: Ronald Hoope, Neddrill

MORNING SESSION PAPERS

WELL CONTROL TRAINING AND USE OF FULL SCALE RIG FLOOR SIMULATION
by Gerrit van Wilpe, Shell International

LIVE-WELL TRAINING: AN OVERVIEW by Arild Thorsrud, North Sea Drilltrainer

TRAINING FOR HIGH TEMPERATURE, HIGH PRESSURE WELLS by Torben Frederiksen, Maersk

PORTABLE TRAINING DEVICES by Fred S. Mueller, Reading & Bates

ADVANCES IN WELL CONTROL PRACTICE & TRAINING by D. White & C. Lowe, Sedco Forex

12.00 - 12.30 Guest speaker: R.C. Parker, Head of Operations S.I.P.M.

12.30 - 13.45 Lunch

13.45 - 17.30 Afternoon session: Applied Technology I
Session Chairman: Paul Wand, Anadrill

PRESENTATION & UPDATE OF EUROPEAN WELL CONTROL CERTIFICATION (EWCF)
by Michael Cummins, European Well Control Forum

AFTERNOON SESSION PAPERS

USING A KICK SIMULATOR TO ANALYSE A WELL CONTROL INCIDENT by P. Wand, Anadrill

APPLICATION OF THE VOLUMETRIC METHOD by Sverre Kr. Sørskår, Smedvig IPR

RAPID GAS-INFLUX DETECTION FROM SURFACE MEASUREMENTS by B. Monaghan, D. Codazzi,
P. Till, A. Starkey and C. Lenamond, Anadrill

SLIMHOLE KICK DETECTION-OPTIONS AND ANSWERS by Michael R. Taylor, Exlog

DRILLING AT A DEEP HPHT WILD CAT WELL IN THE CENTRAL GRABEN AREA, OFFSHORE
DENMARK by Inge G. Myhre, Statoil

19.00 - 23.00 Visit and dinner Amsterdam

Thursday June 4, 1992

Location: Training Centre "Leeuwenhorst" Noordwijkerhout, The Netherlands

8.30 - 12.00 Morning session: New Technology
Session Chairman: Jan Beijering, Shell International

MORNING SESSION PAPERS

INTERACTIVE WELL CONTROL MANUAL by Kim Poulsen, Maersk

DEVELOPMENT OF PC DECISION SUPPORT TOOL by Svein Fagereng, ITC, ABB, Saga

15000 PSI BOP DESIGN AND CONSTRUCTION STUDY by Peter Nichols, KCA

NEXT GENERATION BOP STACK TARGETED FOR SAGA/SNORRE by Ken Klees, Joe Roche, Hydril

APPLICATION OF THE RESEARCH GAS KICK SIMULATOR, R-MODEL by J. Tullet & L. Wickens,
Atomic Energy Authority

12.00 - 13.00 Lunch

13.00 - 17.00 Afternoon session: Applied Technology II
Session Chairman: Ed Milne, KCA Drilling

AFTERNOON SESSION PAPERS

WELL CONTROL AND KICK DETECTION by Peter Vullingsh and Joniek Hager, Shell International Research

APPLICATION OF TOPHOLE BLOWOUT PREVENTER (THB) by Jean Gardner, Smedvig

PANEL DISCUSSION: HIGHLIGHTING WELL CONTROL ASPECTS OF A SAFETY CASE

IMPROVED METHODS FOR PREDICTION WELLHEAD PRESSURES DURING DIVERTER OPERATIONS
by Adam T. Bourgoyne, Louisiana State University

17.00 - 17.15 Closing remarks G.J. Kreeft, Director European Operations IADC

Improved Method of Predicting Wellhead Pressure During Diverter Operations

by

Adam T. Bourgoyne, Jr., *Louisiana State University*

ABSTRACT

Diverter Systems must be designed to provide back pressures which will not result in fracture at the conductor casing seat. Calculation of the pressure at various points in a diverter system is complicated by sonic flow at the exit, by unusually rapid fluid acceleration in some parts of the system, by temperature changes, and by the possible presence of more than one phase. Previous experimental data have been available only for pipe diameters of less than 6 inches (0.152 m). In this study, experiments were carried out in 8 inch (0.203 m) and 10 inch (0.254 m) model diverter systems at rates sufficient to achieve sonic flow. A wide range of gas and liquid rates were investigated. Based on this work, improved algorithms were developed for predicting diverter entrance and exit pressures. It is recommended that the procedure presented in this work for estimating sonic exit pressures replace the current method adopted in API RP 64 (1991).

INTRODUCTION

In some marine environments where gas may be encountered at very shallow depths, conventional blowout prevention equipment and procedures are likely to be of no benefit. There have been numerous disastrous blowouts resulting from loss of well control after encountering unexpected formation pressures in shallow gas formations. By the time that the crew can recognize that the well has started to flow, the gas has already traveled a considerable distance up the open borehole. If the blowout preventers are closed, the pressure at the casing seat can sometimes build to a value exceeding the formation fracture pressure. If one or more flow paths are opened to the surface, the resulting flow can destroy the foundations of a bottom supported structure and ultimately lead to the formation of a crater. The current solution to this problem is to divert the flow away from a bottom supported rig using a diverter system. However, problems can still occur when flowing pressures are high.

A key element of shallow gas well control is the selection of appropriate conductor casing setting depth that works well with the rig diverter system for the maximum likely formation pressure and productivity in the area of interest. Beck, Langlinais, and Bourgoyne (1987) recommended that the diverter and casing should be designed using a systems analysis approach that considers the gas reservoir, borehole, casing, and diverter linked together as a single hydraulic system. A Systems Analysis procedure (Brown and Beggs, (1977), Crouch and Pack, (1980), and Clark and Perkins, (1980) permits the simultaneous calculation of steady state pressures throughout the well and diverter system. This approach was recently presented in detail in API RP 64 (1991).

One of the problems encountered when using a systems analysis procedure is the need for an accurate prediction of the pressures occurring in the diverter system at potentially high gas flow rates. Calculation of the pressure at various points in a diverter system is complicated by sonic flow at the exit, by unusually rapid fluid acceleration in some parts of the system, by temperature changes, and by the possible presence of more than one phase. Conventional equations and computer algorithms used by petroleum engineers to analyze producing wells cannot be applied with any confidence. The purpose of this study was to obtain experimental pressure and flow rate data on a large scale model diverter system and to use this data to evaluate alternative calculation procedures. Previous experimental data have been available only for pipe diameters of less than 6 inches (0.152 m). In this study, experiments involving two phase (gas-water) flow were carried out in 8 inch (0.203 m) and 10 inch (0.254 m) model diverter systems at rates sufficient to achieve sonic flow. Of primary concern was the determination of the exit pressure of a diverter system at flow rates sufficient to cause the flow velocity to reach the sonic velocity.

EXPERIMENTAL PROCEDURE AND RESULTS

Figure 1 is a schematic of the main elements of the experimental apparatus. Air stored in a 290 bbl (46.11 m³) insulated pressure vessel was released through the model diverter by means of a hydraulically operated full open 12-in. (0.305 m) ball valve. The flow rate from the tank was determined by monitoring the decrease in tank pressure and temperature with time. Downstream of the ball valve, a concentric reducer was used to decrease the pipe internal diameter to either 10.02 in. (0.254 m) or 7.891 in. (0.203 m). The length of the model diverter pipe downstream of the concentric reducer was 24 ft (7.32 m) and the overall length of the piping extending from the tank was 32 ft (9.75 m). A 0-100 psi (0-690 kPa) pressure transducer was located 5.5 in. (0.15 m) from the exit to determine the exit pressure. A 0-160 psi (0-1100 kPa) transducer was located 10 ft (3.05 m) upstream from the exit transducer. Data collection was achieved using both a data acquisition computer and analog charts. Table 1 gives typical experimental results achieved using the apparatus.

DETERMINATION OF SONIC EXIT PRESSURE

API RP 64 states "The back pressure for critical flow must be considered and is used as the initiation point for the vent line pressure traverses. The method introduced by Gilbert is used to predict the two phase critical flow back pressure. This empirical technique has stood the test of time (since 1954) and reasonably approximates the laboratory values developed by Beck, Langlinais, and Bourgoyne" (1986). The Gilbert Equation is given in API RP 64 as Equation (A-6), which is shown below for convenience. The two phase pressure, P_{tp} , in psia is given by



$$P_{tp} = \frac{7.435 q R^{0.456}}{S^{1.89}} \quad \text{A-6}$$

where q is the liquid flow rate in barrel per day, R is the gas-liquid ratio in thousands of cubic feet per barrel, and S is the choke diameter in 64th of an inch.

We were surprised to see a choke equation recommended for use at an open pipe exit so we checked the agreement between our 1986 data and Equation A-6. The predicted values obtained using Equation (A-6) were consistently larger than the observed values previously published (1986), often by more than a factor of 3. Equation (A-6) was also tested using the new experimental data for the larger pipe sizes and the results were similar. Typical results are shown in Table 2.

RECOMMENDED ALGORITHM

In order to define the relationship between pressure and steady-state flow rate at any point in the diverter, it is best to assume various flow rates and then calculate the resulting pressure at the point of interest. In this manner, a plot of pressure versus flow rate can be obtained. The starting point for the calculation is the diverter exit, from which one moves by small steps to the point of interest. After assuming a flow rate, the next step is to assume the pressure is atmospheric at the exit and determine the resulting exit velocity. If the calculated velocity is greater than sonic velocity for the fluid, then the assumption of atmospheric pressure was incorrect and a higher pressure exists at the exit. The exit pressure will rise to a value such that the exit velocity is equal to the sonic velocity. It is recommended that the relationship between exit pressure and flow rate for sonic flow is determined using the following equations:

Exit Velocity

$$v_e \leq \sqrt{\frac{1}{\rho C}} = \frac{1}{A} \left[q_g \frac{R_g}{P} \frac{T}{T_g} Z + q_l + q_s \right]$$

$$\rho_e = x_g \frac{PM}{ZRT} + x_l \rho_l + x_s \rho_s$$

$$C_e = x_g \frac{1}{n_p} + x_l C_l + x_s C_s$$

Single Phase Gas

$$n = \frac{C_p}{C_v} = k$$

Multi-phase Flow

$$n = k + f(x_g)$$

For multiphase flow, the effective two phase density and compressibility can be calculated as shown above using the weight fraction γ of the various phases. For most accurate results, the two phase effective n value should be obtained using the new correlation presented in Figure 2. However, even without this correction, the results are acceptable. Shown in Table 2 is a comparison between calculated and observed values of diverter exit pressures. Once the pressure p at the exit is known, the pressure gradient is computed using the following equations:

$$\frac{dp}{dL} = \left[\frac{dp}{dL} \right]_f + \left[\frac{dp}{dL} \right]_g + \left[\frac{dp}{dL} \right]_a$$

friction hydrostatic acceleration

$$\left[\frac{dp}{dL} \right]_f = \frac{f \bar{\rho} \bar{v}^2}{2 d}$$

$$\left[\frac{dp}{dL} \right]_g = \bar{\rho} g \cos \theta$$

$$\left[\frac{dp}{dL} \right]_a = \frac{\bar{\rho}_1 \Delta v^2}{2 \Delta L}$$

The acceleration component of the pressure gradient in a diverter is often the largest term and should not be neglected. The only time the acceleration term should not be used is when a sudden decrease in diameter occurs when moving upstream. An example of this would be at a less than full open wellhead spool. Velocity head is generally not recovered downstream of a restriction if a diffuser is not present. Most accurate results are obtained when the upstream density is used in computing the acceleration term. This requires an iterative approach, but this is easily done with modern spreadsheet software.

It is recommended that adiabatic flow is assumed instead of isothermal flow. Temperature changes associated with the rapidly expanding gas can be significant. The temperature change between points can be computed using:

$$\left[X_g C_{p_g} + X_l C_{p_l} + X_s C_{p_s} \right] \Delta T = \frac{\Delta v^2}{2}$$

Convenient distance step sizes can be assumed when using the pressure gradient to move upstream in a stepwise manner. It is often convenient to choose a step size that will end on a fitting boundary where a diameter change or bend occurs.

REFERENCES

- API RP 64, "Recommended Practices for Diverter Systems Equipment and Operations", First Edition, American Petroleum Institute, Washington, D.C., July 1, 1991
- Beck, F.E., Langlais, J.P., and Bourgoyne, A.T.: "Experimental and Theoretical Considerations for Diverter Evaluation and Design," SPE 15111, California Regional Meeting of SPE, Oakland, California, April 3-6, 1986.
- Beck, F.E., Langlais, J.P., and Bourgoyne, A.T.: "An Analysis of the Design Loads Placed on a Well by a Diverter System," SPE/IADC 16129, Drilling Conference, New Orleans, La., March, 1987.
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NOMENCLATURE

A	Cross sectional area, m^2
C	Compressibility, Pa-1.
C_p	Heat capacity at constant pressure, J/kg/oK.
C_v	capacity at constant vHeat olume, J/Kg/oK
d	Diameter, m.
k	Ratio of heat capacity at constant pressure to heat capacity at constant volume.
f	Moody friction factor.
n	Polytropic expansion coefficient.
p	Pressure, Pa. Also psia in Equation (A-6).
q	Volumetric flow rate, m^3/s . Also liquid flow rate in Equation (A-6), bbl/d
r	Radius, m
R	Universal gas constant. Also gas-liquid ratio in Equation (A-6), Mcf/bbl
S	Diameter, 64th in.
T	Temperature, oK
v	Velocity, m/s
e	Roughness, m
χ	Weight fraction or quality.
μ	Viscosity, Pa-S
θ	Vertical deviation angle, rad.
ρ	Density, kg/m^3

Supscripts:

1,2	Reference points (1 is upstream).
g	Gas.
l	Liquid.
s	Solid. Also standard condition.
tp	Two-phase.

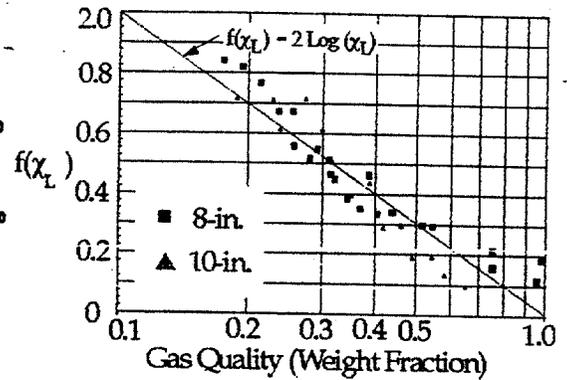
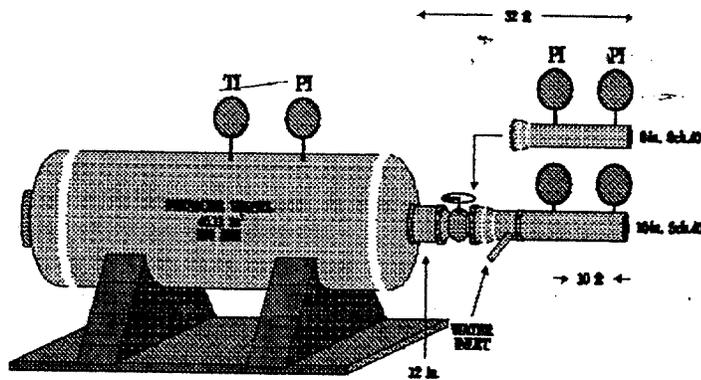


Figure 1 - Schematic of Experimental Apparatus

Figure 2 - Multiphase Sonic Velocity Correction

d= 0.2027 m						d= 0.2545 m					
Gas Rate	Water Rate	Tank Temp	Entrance Pressure	Middle Pressure	Exit Pressure	Gas Rate	Water Rate	Tank Temp	Entrance Pressure	Middle Pressure	Exit Pressure
m ³ /s	m ³ /s	o K	kPa	kPa	kPa	m ³ /s	m ³ /s	o K	kPa	kPa	kPa
48.76	0.00000	295	1089	724	497						
56.30	0.00000	289	933	623	430	75.76	0.00000	282	1,098	289	487
48.06	0.00000	281	799	532	368	61.53	0.00000	267	863	289	411
41.77	0.00000	275	689	459	316	50.02	0.00000	254	679	289	322
35.78	0.00000	268	594	385	272	40.95	0.00000	241	541	263	256
31.82	0.00000	262	515	342	235	32.20	0.00000	231	432	207	203
28.23	0.00000	257	446	297	204	26.99	0.00000	221	350	166	164
23.85	0.00000	252	388	259	176	23.45	0.00000	212	289	134	134
20.67	0.00000	247	340	226	153	18.45	0.00000	204	235	111	109
52.79	0.00114	291	959	613	420	67.09	0.00423	281	858	537	401
43.31	0.00227	282	827	528	359	50.86	0.00321	269	704	431	307
33.63	0.01374	275	729	448	301	38.58	0.00243	258	591	363	241
25.12	0.02623	269	653	412	256	29.54	0.00186	250	509	318	202
20.64	0.03339	265	602	372	230	23.15	0.00146	243	447	269	170
18.43	0.03691	261	551	327	208	18.68	0.00118	237	401	228	145
14.99	0.04009	257	512	304	187	15.42	0.00097	232	362	191	127
13.76	0.04202	254	479	277	172	11.64	0.00073	228	332	170	112

Table 1 - Experimental Results

Evaluation of Eqn A-6					Algorithm Results - d = 10.02 in. (0.253 m)							
Pipe ID. (in.)	GAS RATE (MMSCF/D)	WATER BBL/MM	EXIT PRESSURE		GAS RATE MMCF	LGR Bbl	GAS WEIGHT FRAC	EXIT Obs (psia)	PRES Calc (psia)	EXIT Obs (psia)	PRES Calc (psia)	
			OBS (Psia)	CALC (Psia)								d
7.891	103.0	70	43.7	104	205	67.1	17	0.93	58	56	401	384
	76.6	180	37.1	119	155	50.9	57	0.79	45	44	307	302
	63.0	279	33.4	119	153	50.0	0	0	37	38	256	263
10.02	205.0	17	58.2	69	118	38.6	128	0.76	35	35	241	244
	155.0	57	44.6	91	98.2	32.2	0	0	24	24	164	161
10.02	118.0	128	35.0	100	90.1	29.5	217	0.50	29	29	202	200
	90.1	217	29.3	97	70.6	23.2	316	0.41	25	24	176	166

Table 2 - Comparison of Observed and Calculated Exit Pressures

