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Kern River Field Test of a Steam Quality Measurement Technique

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ABSTRACT

In large steamflood operations, there is a need to measure accurately the steam quality and mass flow rate at the injection wellhead. At Texaco's steamflood operation at the Kern River Field in Bakersfield, California, a novel technique which incorporates an orifice plate in series with a critical flow choke has been developed and tested in the field.

Results from field testing proved the technique to be a potentially viable, low- cost and reasonably accurate method with an accuracy of +/- 5 quality points for steam quality and +/- 32 BSPD-CWE [5.09 m^3/day - CWE] for flow rate. The method was tested at steam qualities ranging from 15 to 88% and at mass flow rates ranging from 200 to 800 BSPD-CWE [32 to 121 m^3/day - CWE]. Upstream pressures ranged from 300 to 700 psia [2068 to 4826 kPa].

INTRODUCTION

Why measure steam quality in large steamflood operations? In Texaco's Kern River Field steamflood, over 20,000 equivalent barrels per day [3180 m^3/day] of oil are burned as fuel to provide wet steam for distribution throughout the field. The ability to measure steam quality and mass flow rate throughout the injection network could potentially reduce generator fuel requirements by optimizing the delivery of steam. Steam quality measurement would enable engineers to detect patterns with low heat injection rates at remote points in the field and correct them to boost recovery from these patterns. In addition, the ability to measure steam quality and mass flow rate at steam injection wells would dramatically improve our ability to predict bottom hole steam quality in an injection well. Improved model studies could increase our ability to optimize recovery from thermal reservoirs.

Because of the large number of steam injection wells in commercial steamfloods, it is important that a wellhead steam quality measurement device be low-cost and durable. For example, in the Kern River Field there are more that 1500 injectors.

Critical flow chokes are typically installed at steam injection wellheads to control steam injection rate. However, both steam quality and mass flow rate cannot be determined from this device alone. The addition of the orifice plate upstream of the critical flow choke provides a second device so that independent equations for mass flow rate through each of these devices can be solved simultaneously to determine an expression for steam quality. By taking advantage of the existing chokes, the addition of an orifice plate gives a

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References and illustrations at end of paper.

simple, practical way of determining steam quality.

This paper presents a field test of this simple technique at Texaco's Kern River Field.

THEORETICAL DEVELOPMENT

The use of the orifice plate in series with a critical flow choke provides a method of measurement for both steam quality and mass flow rate. Neither the orifice plate nor choke alone can be used to measure steam quality and mass flow rate. However, an expression for steam quality through both devices is obtained by solving an independent mass flow rate equation for each device - an equation for wet steam through the critical flow choke and an equation for wet steam through a sharp-edged orifice plate.

Choke Equation

The Napier[1] equation for critical flow through a choke modified for wet steam by King and Crocker[2] is

$$G = 2.057\frac{P}{X^{0.5}}, \quad \ldots\ldots (1)$$

where G is the critical mass flux in the choke, P is the absolute pressure upstream of the choke and X is steam quality upstream of the choke. The units of all terms are defined in the Nomenclature. Converting this equation to yield steam mass flow rate in BSPD-CWE gives

$$W = 2.767\frac{c^2P}{X^{0.5}}, \quad \ldots\ldots (2)$$

where c is the choke bore diameter and W is the mass flow rate of wet steam. For this field test, the exponent on steam quality "b" and the constant "a" are considered to be empirical constants whose values are determined by the regression analysis of our field data i.e.,

$$W = a\frac{c^2P}{X^b}. \quad \ldots\ldots (3)$$

Orifice Plate Equation

Equation (3) gives mass flow rate through the choke as a function of pressure and steam quality upstream of the choke. Likewise, mass flow rate through the orifice plate must be expressed as a function of the differential pressure drop across the orifice plate and steam quality. The James[3] equation for the flow of wet steam through a sharp-edged orifice can be expressed as

$$W = \frac{24.65C_od^2Y}{\left[1-(d/D)^4\right]^{0.5}}\left(\frac{\phi}{X^{1.5}(\upsilon_g-\upsilon_f)+\upsilon_f}\right)^{0.5}, \quad \ldots\ldots (4)$$

In this equation, C_o is the discharge coefficient; d is the diameter of the orifice plate; Y is the vapor expansion factor; ϕ is the differential pressure; D is the inside diameter of the meter run; X is the steam quality; υ_f and υ_g are the specific volumes of saturated water and steam at the pressure upstream of the choke. For steam qualities greater than 10%, the specific volume of water is small relative to the specific volume of steam and can therefore be neglected. The specific volume of steam vapor at pressures between 100 and 1000 psia [689 and 6895 kPa] can be expressed as

$$\upsilon_g = \frac{C_1}{P^{C_2}}, \quad \ldots\ldots (5)$$

where:

C_1	C_2	P
376.204	0.9640	100-300
486.340	1.0009	300-700
783.514	1.0817	700-1000

Substituting equation (5) into equation (4) and assuming υ_f is small relative to υ_g gives

$$W = \frac{24.65C_od^2Y}{C_1\left(1-(d/D)^4\right)^{0.5}}\left(\frac{\phi P^{C_2}}{X^{1.5}}\right)^{0.5}. \quad \ldots\ldots (6)$$

This equation expresses mass flow rate through an orifice for pressures between 100 and 1000 psia [689 and 6895 kPa] and steam qualities between 10% and 100%. We now have two algebraically simple expressions relating mass flow rate and steam quality through the choke, equation (3), and through the orifice plate, equation (6).

Simultaneous Solution

Substituting equation (3) into equation (6) and solving for the steam quality give expressions for steam quality and mass rate through the device as

$$X = \left(\frac{607.62C_o^2(d/c)^4Y^2\phi}{C_1a^2\left[1-(d/D)^4\right]P^{2-C_2}}\right)^{1/1.5-2b}, \quad \ldots\ldots (7)$$

$$W = a\frac{c^2P}{X^b}. \quad \ldots\ldots (8)$$

The value of C_O according to James[3] is

$$C_o = 0.61, \qquad (9)$$

however, in this test, C_O is considered as an empirical factor to be determined from the field data. The vapor expansion factor Y corrects for the compressibility of steam which adiabatically expands as it passes through the orifice plate. Determination of the vapor expansion factor Y is included in the Appendix.

DESCRIPTION OF FIELD TEST

Choke In Series With An Orifice Plate

Figure 1 shows a plan and elevation view of a meter run in a 2-inch, schedule 40,(2.067 inch ID [5.26 cm]) steam line from a dedicated 12 MMBtu/hr [3.5 MW] steam generator to an injection well. The meter run consisted of a 2-inch (2.067 inch ID [5.26 cm]) meter tube with inline straightening vanes upstream of a 1/8 - inch [0.318 cm] thick sharp-edged orifice plate. Orifice plates used during the test were 1-inch [2.54 cm], 1.25-inch [3.17 cm], and 1.50-inch [3.81 cm]. A critical flow choke assembly which incorporated flow beans with bore diameters from 21 to 44 64ths of an inch [0.831 to 1.74 cm] was located downstream of the flange connected orifice plate. Between the orifice plate and the choke, the absolute pressure was measured with a pressure transducer while the differential pressure across the orifice plate was measured with a differential pressure transducer. The positioning of the orifice plate and straightening vanes in the meter run were according to the A. G. A. piping installation code for a 2-inch meter run.

Test Range And Procedure

A total of 200 test points were measured covering steam mass flow rates from 200 to 800 BSPD-CWE [32 to 121 m^3/day - CWE] and steam qualities from 15% to 88% . Choke beans were sized to achieve these design rates and qualities by assuming a 500 psia pressure upstream of the choke. Once the feedwater flow rate through the generator was established using a positive displacement pump, the fuel rate to the generator was adjusted to achieve a given steam quality. The steam quality from the generator was determined by measuring the mass flow rate of feedwater entering the generator with a turbine meter. From these measurements, the steam quality being discharged from the generator was determined from orifice plate data.

From a known mass rate through the orifice plate, the James Equation (4) can be used to calculate the known steam quality, using an orifice discharge factor of 0.61, flowing from the generator. To validate this procedure, spot checks of steam quality were made using the comparative conductivity technique.

TEST DATA

A total 200 test points were actually taken. Of these 90 points were eliminated because of instability of the generator at the times these points were taken or because the data points collected were redundant. Instability of the steam generator was detected by large fluctuations in discharge pressure and feedwater rate. These fluctuations may have resulted from improper combustion in the generator, lack of dampening on the feedwater positive displacement pump, or unexpected low backpressure.

The remaining 110 data points are representative of data collected at stable conditions and are shown in Table 1. Data recorded for each test point were the steam pressure between the orifice plate and the choke, differential pressure across the orifice plate, feedwater volumetric flow rate, choke bean diameter, orifice plate diameter, and the measured steam quality.

DISCUSSION OF RESULTS

Using the data in Table 1, an exponential least squares analysis of equation (3) gave the following regression constants

$$a = 2.5253, \qquad (10a)$$

and

$$b = 0.466. \qquad (10b)$$

Solving equation (7) for the discharge coefficient C_O of the orifice plate for each test point in Table 1 using equations (10a) and (10b) gave an average discharge coefficient of

$$C_o = 0.60. \qquad (11)$$

Therefore, the final regression equations for steam quality and mass flow rate are

$$X = \left(\frac{95.28 C_o^2 (d/c)^4 Y^2 \phi}{C_1 [1 - (d/D)^4] P^{2-C_2}} \right)^{1.7606}, \quad \ldots\ldots\ldots\ldots (12)$$

and

$$W = 2.5253 \frac{c^2 P}{X^{0.466}}, \quad \ldots\ldots\ldots\ldots (13)$$

where P is between 300 and 700 psia [2068 and 4826 kPa], and steam quality X is between 15% and 88%. Table 2 shows the measured steam quality and mass flow rate compared with the predicted values using the above equations for each test point. The average steam quality deviation was +/- 4.6 quality points or an average error of 12.6%. The average mass flow rate deviation was +/- 31.9 BSPD-CWE [5.07 m^3/day - CWE] or an average error of 8.7%. Figures 2, 3, 4, 5, 6, and 7 show the measured versus predicted steam quality and steam mass flow rate for the test data grouped by common orifice plate size.

Figure 8 shows the measured steam quality and rate data as well as the correlation equations plotted in a general form for an arbitrary pressure, choke diameter, orifice size, and pipe diameter. The abscissa and ordinate coordinates of this plot were developed from equations (12) and (13). To use this plot to determine steam quality, the expression on the left ordinate must be evaluated from the geometry of the choke and orifice plate and the measured absolute and differential pressures. The steam quality is determined by the intersection of a horizontal line from this value and the steam quality curve. By evaluating the intersection of a vertical line through the predicted steam quality and flow rate curve, the value of the rate expression can be determined. The right ordinate expression can then be solved for the steam mass flow rate.

APPLICABILITY OF THE DEVICE

This device is applicable to steamflood operations in which critical flow chokes are used to control steam injection rate. By design, critical flow chokes spoil about 50% of the pressure upstream of the chokes. For shallow injection wells this does not present a problem because of the relatively low wellhead injection pressures. For deep wells, however, critical flow chokes are rarely used because the high wellhead pressures at injectors coupled with the chokes would require very high generator pressures. Appropriate methods and techniques suitable for deep wells are under development at Texaco's E & P Technology Division.

CONCLUSIONS

- A low cost field oriented steam quality meter has been developed and field tested which utilizes an orifice plate upstream of a critical flow choke to determine both steam quality and mass flow rate. Given the geometry of the choke and orifice plate, the static pressure upstream of the choke, and differential pressure across the orifice plate, the meter outputs quality and rate.
- Test data (110 test points), taken from Texaco's Kern River Field, were used to determine empirical constants in equations for predicting steam quality and mass flow rate. Predicted steam quality differed from measured steam quality by +/- 4.6 quality points while steam mass flow rate differed by +/- 31.9 BSPD-CWE [5.07 m^3/day - CWE].
- This device is applicable for measuring steam quality and mass flow rate at injection wells in which critical flow chokes are used. This device is not applicable for steam injection wells in deep reservoirs due to the high pressures required to overcome the 50% reduction through critical flow chokes.

NOMENCLATURE

a = Regression constant in equation (3) (dimensionless)

b = Regression constant in equation (3) (dimensionless)

c = Choke bore diameter (in.)

C_1, C_2 = Constants in equation (5) (dimensionless)

C_o = Discharge coefficient of orifice plate (dimensionless)

d = Diameter of orifice plate (in.)

D = Inside diameter of meter run (in.)

G = Critical mass flux in choke (lbm/ft^2-sec)

P = Absolute pressure upstream of choke and downstream of orifice (psia)

r = Pressure ratio across orifice (dimensionless)

W = Mass flow rate through orifice/choke (bspd-cwe)

X = Steam quality upstream of choke (fraction)

Y = Steam vapor expansion factor (dimensionless)

ϕ = Differential pressure across the orifice (in. of water)

υ_f = Specific volume of saturated water at a pressure upstream of the orifice (ft^3/lbm)

υ_g = Specific volume of saturated steam at a pressure upstream of the orifice (ft^3/lbm)

γ = Specific heat ratio (dimensionless)

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APPENDIX

Vapor Expansion Factor

The vapor expansion factor, Y, in equation (4) as given by James[3] is

$$Y=\sqrt{r^{2/\gamma}\left(\frac{\gamma}{\gamma-1}\right)\left(\frac{1-r^{\frac{\gamma-1}{\gamma}}}{1-r}\right)\left(\frac{1-(d/D)^4}{1-(d/D)^4 r^{2/\gamma}}\right)}, \quad \text{....(A-1)}$$

where the pressure ratio across the orifice can be calculated as

$$r=\left(1+\frac{\phi}{27.692P}\right)^{-1}. \quad \text{.......(A-2)}$$

The specific heat ratio of steam used in equation (A-1) is

$$\gamma=1.3. \quad \text{.......(A-3)}$$

TABLE 1

TEST DATA

No.	Pressure (psig)	Differential Pressure (in. w.c.)	Feedwater Rate (bwpd)	Bean Size (64ths in.)	Orifice Diameter (in.)	Steam Quality (fraction)
1	450.4	34.3	215.5	21	1.00	0.2951
2	455.4	34.2	208.6	21	1.00	0.3113
3	522.1	45.4	187.2	21	1.00	0.4902
4	659.4	72.4	194.1	21	1.00	0.7622
5	333.7	56.5	297.0	26	1.00	0.2191
6	334.8	53.0	298.0	26	1.00	0.2080
7	508.3	110.4	299.2	26	1.00	0.4626
8	515.1	111.8	297.3	26	1.00	0.4755
9	629.4	164.0	304.0	26	1.00	0.6944
10	615.3	162.0	310.0	26	1.00	0.6591
11	660.7	190.7	304.9	26	1.00	0.7944
12	654.7	182.8	314.9	26	1.00	0.7328
13	315.8	83.0	371.8	30	1.00	0.2008
14	601.2	254.1	406.0	30	1.00	0.6059
15	611.9	258.7	406.0	30	1.00	0.6214
16	603.5	254.9	406.3	30	1.00	0.6083
17	687.0	324.9	415.2	30	1.00	0.7654
18	682.2	326.8	415.5	30	1.00	0.7638
19	679.1	325.9	416.6	30	1.00	0.7571
20	324.0	108.8	516.9	32	1.00	0.1493
21	510.9	257.9	508.2	32	1.00	0.3951
22	503.5	254.6	510.1	32	1.00	0.3853
23	370.8	184.3	598.8	35	1.00	0.1949
24	362.0	169.8	602.9	35	1.00	0.1781
25	490.4	341.0	589.8	35	1.00	0.3766
26	489.9	332.4	592.9	35	1.00	0.3667
27	342.9	7.6	224.8	21	1.25	0.1542
28	348.4	8.2	203.3	21	1.25	0.1948
29	444.9	13.9	194.7	21	1.25	0.3605
30	594.4	23.8	213.9	21	1.25	0.5640
31	305.0	14.6	270.9	25	1.25	0.1797
32	307.9	15.5	267.5	25	1.25	0.1931
33	485.7	34.3	320.6	25	1.25	0.3551
34	486.1	33.8	320.6	25	1.25	0.3515
35	588.4	47.8	287.0	25	1.25	0.6044
36	597.5	48.8	283.8	25	1.25	0.6297
37	320.3	32.2	407.0	29	1.25	0.1815
38	304.4	29.5	392.7	29	1.25	0.1737
39	514.4	67.2	403.5	29	1.25	0.4307
40	514.3	69.4	397.9	29	1.25	0.4497
41	576.5	91.7	400.2	29	1.25	0.5887
42	577.5	91.3	401.7	29	1.25	0.5845
43	703.3	128.6	400.9	29	1.25	0.8555
44	710.2	129.9	398.1	29	1.25	0.8759
45	344.1	68.1	614.9	35	1.25	0.1780
46	348.8	68.4	614.0	35	1.25	0.1805
47	522.4	165.6	590.7	35	1.25	0.4785
48	518.7	168.4	591.1	35	1.25	0.4813
49	574.3	206.7	599.5	35	1.25	0.5853
50	575.3	207.2	597.1	35	1.25	0.5904
51	689.0	272.3	608.3	35	1.25	0.7903
52	690.2	272.1	609.9	35	1.25	0.7880
53	376.1	96.9	691.8	38	1.25	0.2059
54	372.1	95.9	693.0	38	1.25	0.2024
55	503.1	200.1	700.0	38	1.25	0.4173
56	499.0	195.4	701.2	38	1.25	0.4069
57	576.9	276.3	701.9	38	1.25	0.5748
58	578.3	275.2	702.0	38	1.25	0.5741
59	657.2	356.3	696.3	38	1.25	0.7602
60	659.6	355.6	697.8	38	1.25	0.7590
61	330.2	160.4	795.8	44	1.25	0.2241
62	331.7	162.5	798.3	44	1.25	0.2258
63	428.6	288.9	792.2	44	1.25	0.4068
64	430.1	290.8	797.8	44	1.25	0.4054
65	513.4	418.9	797.2	44	1.25	0.5875
66	520.4	428.0	796.7	44	1.25	0.6025
67	507.9	6.2	196.1	21	1.50	0.4195
68	413.4	9.3	319.1	25	1.50	0.2407
69	484.5	12.8	316.1	25	1.50	0.3430
70	491.4	13.4	291.5	25	1.50	0.4032
71	637.9	21.5	325.9	25	1.50	0.5790
72	695.8	27.0	320.1	25	1.50	0.7414
73	701.5	26.6	319.9	25	1.50	0.7386
74	330.0	13.0	390.9	30	1.50	0.1979
75	323.9	12.8	404.8	30	1.50	0.1830
76	511.5	26.7	422.1	30	1.50	0.3992
77	500.8	26.1	425.8	30	1.50	0.3821
78	384.0	22.3	486.5	32	1.50	0.2351
79	388.6	22.6	482.7	32	1.50	0.2422
80	520.0	38.8	498.5	32	1.50	0.4158
81	519.5	39.5	498.3	32	1.50	0.4212
82	613.0	56.8	502.4	32	1.50	0.6058
83	606.6	57.3	502.4	32	1.50	0.6051
84	712.5	78.1	491.2	32	1.50	0.8686
85	703.5	77.1	497.0	32	1.50	0.8393
86	378.4	25.1	603.6	35	1.50	0.1821
87	374.4	24.7	603.5	35	1.50	0.1786
88	550.0	55.5	600.5	35	1.50	0.4276
89	548.2	59.9	610.4	35	1.50	0.4402
90	633.2	85.3	595.1	35	1.50	0.6494
91	610.1	77.0	609.5	35	1.50	0.5690
92	702.7	102.3	607.9	35	1.50	0.7704
93	701.0	102.4	607.6	35	1.50	0.7701
94	379.2	34.1	698.8	38	1.50	0.1842
95	377.6	34.2	699.9	38	1.50	0.1836
96	480.4	64.0	698.7	38	1.50	0.3458
97	496.8	67.6	698.1	38	1.50	0.3688
98	510.0	71.7	693.4	38	1.50	0.3959
99	611.1	119.0	697.8	38	1.50	0.6387
100	609.7	118.9	702.6	38	1.50	0.6312
101	669.2	147.7	693.8	38	1.50	0.7979
102	668.3	148.8	694.0	38	1.50	0.8009
103	330.0	54.6	802.7	44	1.50	0.1965
104	328.6	53.9	803.7	44	1.50	0.1936
105	429.3	107.7	793.9	44	1.50	0.3893
106	430.1	108.7	795.8	44	1.50	0.3910
107	511.8	165.2	802.7	44	1.50	0.5810
108	513.4	167.7	802.4	44	1.50	0.5887
109	538.0	189.7	783.6	44	1.50	0.6848
110	538.5	189.7	784.6	44	1.50	0.6836

Note: The inside diameter of the meter run was 2.067 inches for all tests. The steam quality shown is calculated using a Co of 0.61 and the measured feedwater flow rate.

TABLE 2

MEASURED VERSUS PREDICTED STEAM QUALITIES AND FLOWRATE

No.	Measured Steam Quality (%)	Predicted Steam Quality (%)	Measured Flowrate (Bspd-cwe)	Predicted Flowrate (Bspd-cwe)
1	29.5	31.9	216	211
2	31.1	31.2	209	215
3	49.0	40.0	187	220
4	76.2	59.5	194	231
5	21.9	28.3	297	255
6	20.8	25.4	298	269
7	46.3	43.8	299	315
8	47.5	43.8	297	319
9	69.4	59.6	304	338
10	65.9	60.6	310	328
11	79.4	70.6	305	329
12	73.3	66.9	315	334
13	20.1	22.5	372	357
14	60.6	50.8	406	462
15	62.1	50.9	406	470
16	60.8	50.8	406	464
17	76.5	61.3	415	484
18	76.4	62.6	416	477
19	75.7	62.8	417	474
20	14.9	22.0	517	421
21	39.5	43.9	508	479
22	38.5	43.9	510	472
23	19.5	23.2	599	559
24	17.8	21.1	603	570
25	37.7	40.5	590	571
26	36.7	39.0	593	580
27	15.4	20.7	225	196
28	19.5	22.8	203	191
29	36.0	37.0	195	195
30	56.4	56.7	214	213
31	18.0	23.0	271	237
32	19.3	25.0	268	231
33	35.5	45.1	321	275
34	35.2	44.0	321	278
35	60.4	57.4	287	298
36	63.0	58.0	284	301
37	18.2	29.4	407	300
38	17.4	27.6	393	294
39	43.1	46.7	404	385
40	45.0	49.2	398	376
41	58.9	64.9	400	372
42	58.5	64.2	402	374
43	85.5	82.3	401	406
44	87.6	82.4	398	410
45	17.8	26.0	615	495
46	18.1	25.6	614	504
47	47.9	57.5	591	519
48	48.1	59.8	591	507
49	58.5	71.1	600	518
50	59.0	71.2	597	519
51	79.0	83.5	608	576
52	78.8	83.1	610	578
53	20.6	23.4	692	665
54	20.2	23.4	693	659
55	41.7	48.2	700	638
56	40.7	47.0	701	640
57	57.5	65.7	702	635
58	57.4	65.0	702	640
59	76.0	80.7	696	658
60	75.9	80.0	698	663
61	22.4	24.6	796	769
62	22.6	25.0	798	768
63	40.7	42.5	792	775
64	40.5	42.7	798	776
65	58.8	58.3	797	802
66	60.3	59.1	797	808
67	41.9	35.6	196	225
68	24.1	30.5	319	280
69	34.3	40.2	316	289
70	40.3	42.3	292	286
71	57.9	60.9	326	314
72	74.1	77.1	320	308
73	73.9	74.2	320	315
74	19.8	22.7	391	371
75	18.3	22.8	405	364
76	39.9	37.1	422	454
77	38.2	37.0	426	446
78	23.5	28.4	487	442
79	24.2	28.5	483	446
80	41.6	43.7	499	488
81	42.1	45.1	498	481
82	60.6	62.9	502	487
83	60.5	64.9	502	476
84	86.9	83.5	491	498
85	83.9	83.4	497	492
86	18.2	19.5	604	615
87	17.9	19.4	604	611
88	42.8	39.9	601	643
89	44.0	45.4	610	605
90	64.9	64.5	595	595
91	56.9	57.8	610	602
92	77.0	73.6	608	621
93	77.0	74.0	608	618
94	18.4	18.7	699	740
95	18.4	19.0	700	734
96	34.6	36.3	699	693
97	36.9	37.6	698	705
98	39.6	39.7	693	705
99	63.9	68.4	698	660
100	63.1	68.5	703	658
101	79.8	84.3	694	657
102	80.1	85.5	694	652
103	19.6	19.2	803	860
104	19.4	18.9	804	862
105	38.9	38.5	794	811
106	39.1	39.0	796	808
107	58.1	58.7	803	797
108	58.9	59.9	802	792
109	68.5	68.0	784	784
110	68.4	67.9	785	785

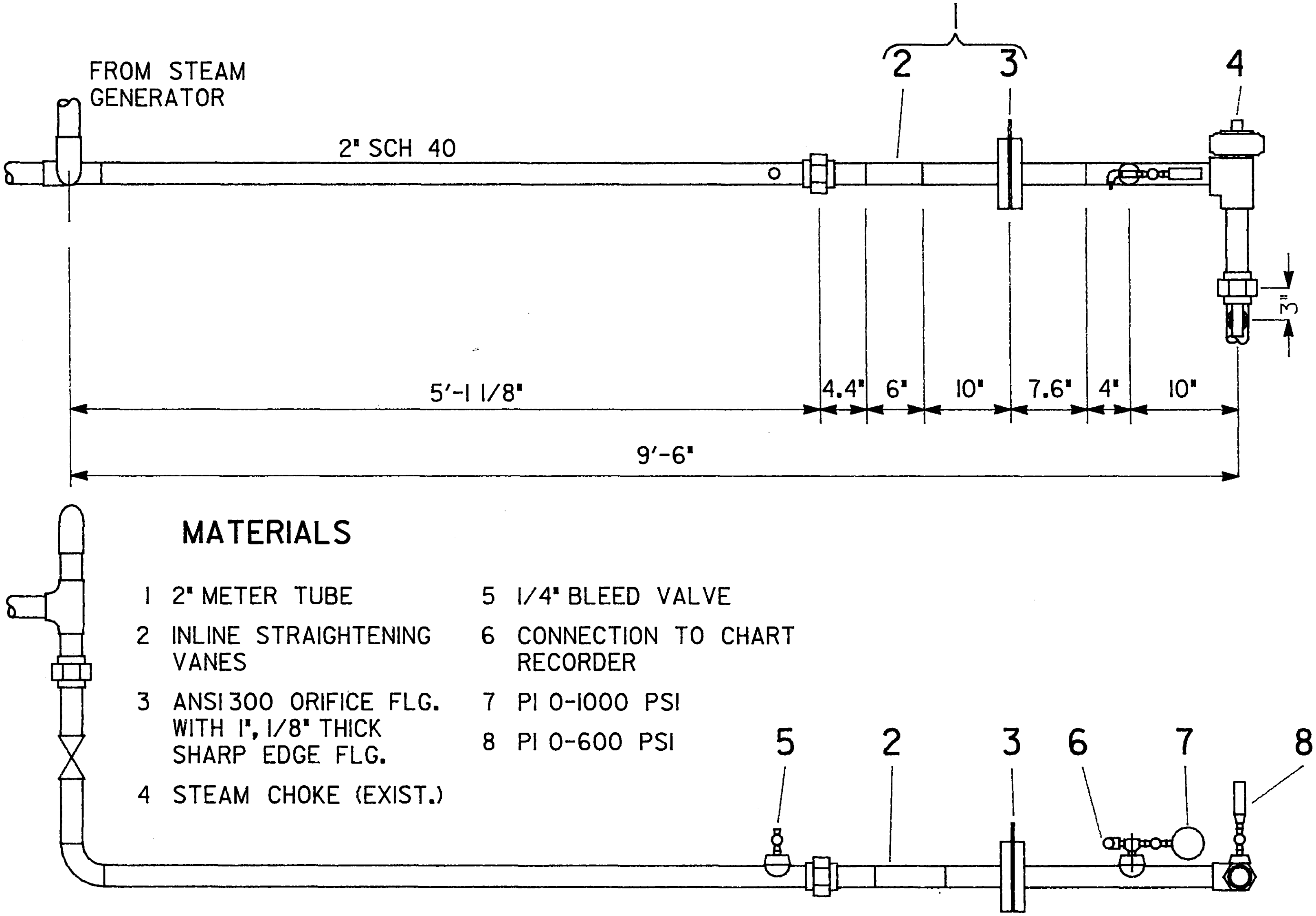

Fig. 1—Plan and elevation views of the orifice/choke meter run.

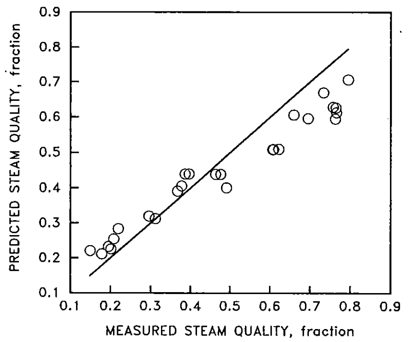

Fig. 2—Comparison of measured and predicted steam quality for 1.00-in. orifice plate.

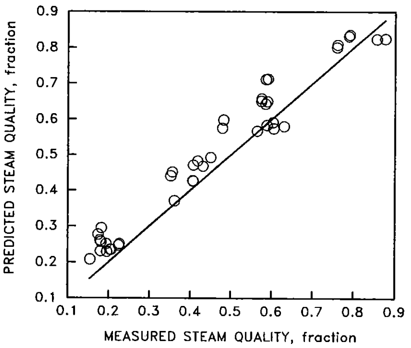

Fig. 3—Comparison of measured and predicted steam quality for 1.25-in. orifice plate.

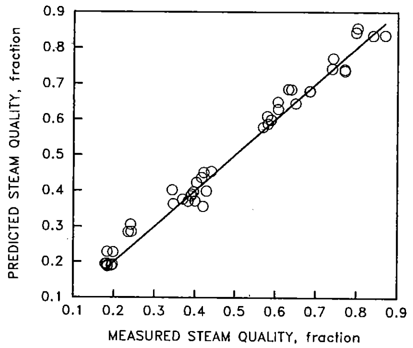

Fig. 4—Comparison of measured and predicted steam quality for 1.50-in. orifice plate.

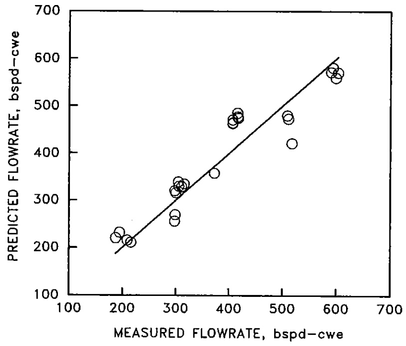

Fig. 5—Comparison of measured and predicted flowrate for 1.00-in. orifice plate.

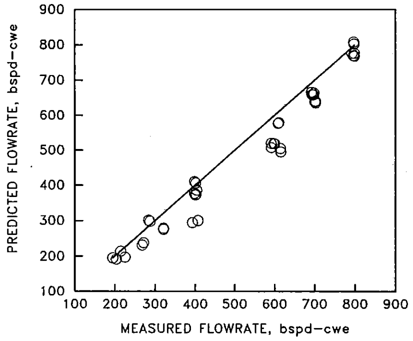

Fig. 6—Comparison of measured and predicted flowrate for 1.25-in. orifice plate.

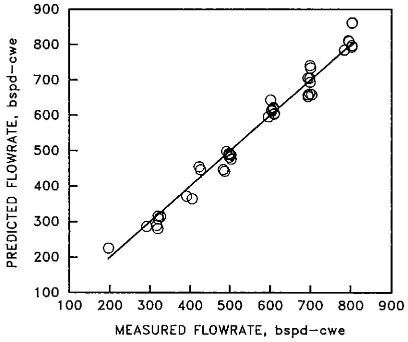

Fig. 7—Comparison of measured and predicted flowrate for 1.50-in. orifice plate.

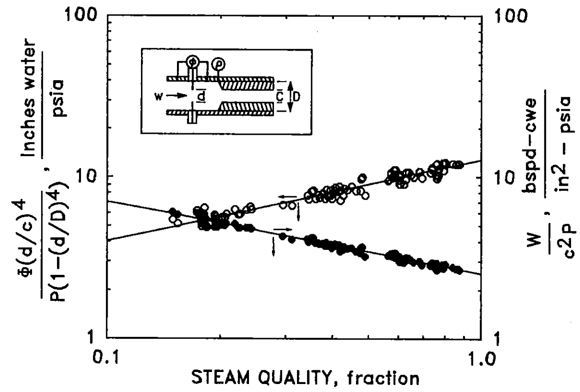

Fig. 8—General pressure, flowrate, and steam quality curve for orifice choke device.