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PRODUCTION EVALUATION AND TESTING OF A HIGH VISCOSITY AND HIGH GAS VOLUME FRACTION MULITIPHASE METER.

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Abstract

Tests were conducted during November, 1995 on the Agar Corporation Inc. MPFM by Conoco, Inc. and Amoco Corporation at the Conoco Multiphase Test Facility near Lafayette, Louisiana, to determine the performance of this novel high gas volume fraction (GVF) multiphase meter. Tests conducted previously on the this high gas volume fraction meter utilized the standard AGAR MPFM for high viscosity, low gravity multiphase well test measurement. These tests were conducted by Conoco and Maraven (Petrozuata) at the San Diego Norte Pilot Plant near Zuata in the Orinoco Oil Belt of Venezuela and were reported in a paper presented by Intervep, Conoco, and Maraven at "Multiphase 95" in Cannes, France in June of 1995.

Subsequent application and testing was performed by BITOR/JVCO at Camp Morichal, Venezuela during the early part of 1996 on heavy Orinoco Bitumen production. Initial results of that test were presented at the IPC Conference in Calgary, Canada, in July, 1996, Paper No. 629 entitled "Field Tests of a High Viscosity Multiphase Meter".

This paper describes how this multiphase meter works, summarizes the results of the field tests (performance and accuracy), and discusses the application of the meter. The high gas volume fraction meter (MPFM-400 Series) utilizes a patented Fluidic Flow Diverter (FFD™) to divert most of the free gas in a multiphase stream around an MPFM-300 multiphase meter and into an ancillary gas measurement loop. The gas flow rate in the bypass loop is metered accurately and added to the oil, water, and gas volumes measured by the multiphase meter. The result is a high void fraction multiphase meter which can accurately meter flow streams where the gas phase is a dominant component of the flow. This novel concept reduces the size and cost of the multiphase meter while improving its capacity and accuracy. The field tests conducted at the Conoco Multiphase Test Facility determined that the meter can handle flow conditions with the gas-oil ratio (GOR) of 20 to 90,000 SCF/BBL with very good accuracy. The MPFM-400 Series Meter has important applications for metering high GOR wells or wells with moderate GOR that are tested at low pressure.

1. INTRODUCTION

High viscosity fluids measurement necessitates some special consideration for multiphase measurement, primarily in the software and physical attributes. High gas to liquid ratio (GLR) production streams pose a set of special problems to multiphase metering. These problems have been reviewed, and methods for partial separation to deal with high GLR streams have been presented previously (1, 2).

The need for high GLR capabilities of a multiphase meter is illustrated in Figure 1. The graph in Figure 1 shows a sample of well characteristics (gas to liquid ratios) from different production regions around the world. It should be noted that a significant percentage of the wells have gas fraction above the 90 to 95% gas volume fraction.

The MPFM-400 ("High GVF Meter"), which can measure accurately with a GVF of 99.9%, is an extension of the MPFM-300 Series ("Multiphase Meter"), which is limited to an average GVF of 97.5%. The principles of operation and performance of the Multiphase Meter have been described in detail in References 3, 4 and 5. The Multiphase Meter measures the total volume of the flowing stream utilizing a ruggedized PD (Positive Displacement) meter, a Venturi section to measure gas/liquid flow rates, and a Water Cut Monitor for determination of the water/liquid fraction. The outputs of these devices are fed into a computer which houses the proprietary data management software. The software is designed to provide flow rates of oil, water and gas phases in the multiphase stream.

The High GVF Meter is designed to accurately measure flow streams with very high GLR's. Using the unique FFD™, the meter routes varying amounts of the free gas in the inlet stream into the gas bypass loop as shown in Figure 2. The high viscosity version of the MPFM utilizes only the liquids portion of the meter without provision of any gas diversion. The diverter innovation allows the High GVF Meter to handle a much higher total rate of multiphase fluids. The unique design approach reduces the overall size of the equipment which would otherwise be required, and lowers the overall cost of the system.

Figure 2 is a drawing of the High GVF Meter. The fluid stream enters the meter through the FFD™ which diverts a major portion of the free gas in the inlet stream to the gas bypass loop. The remaining fluids pass into the Multiphase Meter. The FFD™ device is a mechanical device with no moving parts that utilizes the difference in the flow momentum of the gas and liquid to operate as a fluidic diverter. The lower flow momentum of the gas causes the FFD™ to deflect most of the gas in the inlet stream to the gas bypass loop. The higher momentum of the remaining liquid/gas mixture in the stream induces continuation of the flow through the Multiphase Meter.

The diverted gas in the gas bypass loop flows through the gas metering segment where the flow rate is measured. The gas bypass loop stream and the Multiphase Meter stream recombine downstream of the unit and exit the system.

During the above process, the Multiphase Meter has measured the oil, water, and gas phases of the stream running though it. The gas measured by the gas bypass loop is then added to the measurement of the gas phase flowing through the Multiphase Meter to completely account for all fluids in the original stream. The specified accuracy and capacity for a number of common High GVF Meter models are shown in Table 1.

The field tests conducted at the Conoco Multiphase Test Facility used a 2" model of the High GVF Meter. The objective of the field evaluation was to determine that the accuracy specifications shown in Table 1 can be attained under realistic field conditions.

2. THE CONOCO MULTIPHASE TEST FACILITY

The Multiphase Flow Test Facility, which was built for the purpose of evaluating multiphase flow meters, is located within Conoco's North Maurice Field production facility, approximately 10 miles southwest of downtown Lafayette, Louisiana. In this producing field there are four gas condensate wells that feed into the production facility at a rate of approximately 30 MMSCFPD and 3,000 BFPD. The test facility is capable of handling up to 7,000 barrels per day each of water and oil (combined 14,000 BPD) and 2 MMSCF of gas per day. The facility is unique in that a matrix of tests can be performed for varying flow rates, pressures, volume fractions, GLR, water cuts, and installation effects to simulate various production operations. Table 2 shows the testing capabilities and the fluid properties used in the tests described in this report. Figure 3 shows the schematic of the test facility.

The fluids used in the test facility are produced fluids from the North Maurice Field. A small portion of the gas from the facility process trains is combined with oil and water acquired from volumes accumulated in the field facility tanks and measured by the primary reference meters. The oil and water are drawn from the tanks and surge vessel and mixed with the gas which is injected into the stream. The combined stream is measured by the multiphase meter and then separated. The gas is compressed and routed to the gas sales line. The liquids are separated, with the water being dumped into the facility water disposal system, and the oil accumulated in the surge vessel.

The testing facility is equipped with reference meters so that each single phase is measured before combining into a 3-phase stream. The accuracy of the reference meters is ±0.7%. Data readouts are made continuously in the control room.

Provisions are also available to acquire and store heavier crude oils that can be used as an alternative oil phase. In addition, fresh water, from an on-site fresh water tank, can be used as an alternative to produced brine water.

The Conoco facility was used to conduct extensive performance tests on the multiphase meters. These results were published previously (3). The same facility was selected for the High GVF Meter performance tests so that the improvements in the performance of the two meters could be compared under similar testing environments. Figure 4 shows a 2" High GVF Meter (401 Model) similar to the one used in the field tests.

3. PERFORMANCE TESTS AND THE TEST MATRIX

Figure 5 shows the test matrix used in the current performance tests. Each point in the graph represents a test, characterized by the water cut and the GVF of the stream. Since the High GVF Meter is designed to include high GLR conditions, the test matrix was intentionally biased to look at very high gas volume fractions. To illustrate the relationship between the test matrix and typical field conditions, points 1 to 4 in the graph are converted to well flow rates in Table 3. The tests shown in Figure 5 were conducted at an average pressure of 150 psig and temperature of about 120°F. A pressure/temperature correction is therefore used to convert test points 1 to 4 to simulated well conditions in Table 3.

The liquid and gas superficial velocities used in the tests are shown in Figure 6 along with GVF lines. The range of liquid and gas velocities and GVF parameters used in the tests resulted in various flow regimes being tested.

4. TEST RESULTS

The results of the High GVF tests are summarized in Figures 7 through 10. The High GVF Meter readings for oil, water, and gas phases are compared with the single phase data from the loop which is considered as reference. For the purpose of these tests, the loop rates are considered to be 100% accurate. Since the single phase gas rates in the loop are measured under different pressure and temperature conditions than the meter, a PVT and solubility correction was applied to the reference gas measurements to represent the gas rates under actual test conditions.

A total of 157 tests were conducted during the performance evaluation period. Figures 7 through 11 show the High GVF Meter test results plotted against the reference loop rates for oil, water, gas, liquid and total flow rates. In each plot, the upper and lower accuracy specifications (see Table 1) for the High GVF Meter (Model 401-20) are also drawn as the performance boundary lines. As noted by the plots in Figures 7 through 10, the meter can measure oil, water, gas and liquid rates of a multiphase stream within the accuracy specifications stated in Table 1 under the very wide variety of flow conditions represented by the test matrix. Figure 11 shows the total (oil + water + gas) flow rates as determined by the meter to have an accuracy of about ±2% of reading when compared with reference loop tests.

The high viscosity meter has shown exceptional abilities to measure heavy crude (API 10-18 gravity) and viscosities in the 100 to 1200 centistoke range. Tests on Venezuelan Orinoco Belt Bitumen (8, 9) indicate that heavy, high viscosity multiphase fluids can be measured within ±5%.

5. CAPACITY OF HIGH GVF METER

The field tests conducted at the Conoco Multiphase Test Facility have shown that the High GVF Meter can handle flow conditions with gas volume fractions up to 99.4% with good accuracy within the vendor's specifications. At the 150 psig pressure used in the Conoco tests, the 99.4% GVF corresponds to the GLR of 9,300 SCF/BBL. Since the meter used in these tests was designed to ANSI 600 pressure rating, the same unit could have handled wells with GLR of up to 90,000 SCF/BBL at the maximum operating pressure of 1,440 (ANSI 600).

The tests conducted at the vendor's test loop, combined with the data from the Conoco tests, have indicated that this technology is applicable to other meter sizes. Utilizing the multiphase flow model of Tailtel and Dukler (6) as amended by Xiao (7), the liquid and gas capacities for various size High GVF Meters are calculated as shown in Figure 12. The Flow rates shown in Figure 12 are actual flow rates at 150 psig (10 bars) and 60°F.

6. HIGH GVF AND HIGH VISCOSITY METER APPLICATIONS

The High GVF Meter is intended for applications where gas is the dominant component of the flow stream. This can be in very high GLR wells (gas condensate) or wells with moderate GLR that are tested at low pressure. Figure 13 shows the performance envelope of the 2" High GVF Meter (Model 401-20), with a 4" to 6" gas loop, connected to a 6" flow line operated at 600 psig pressure. The liquid and gas rates are actual rates as seen by the meter. The gas flow rate capacity of the High GVF Meter is a function of the gas bypass loop.

The production rates for 9 wells (Table 4) tested by this meter are also marked in Figure 13 to illustrate the range and turndown capability of the meter. It should be noted that all flow rates shown in Table 4 can be measured with the accuracy stated in Table 1.

As noted by the data in Table 4 and Figure 13, the High GVF Meter can handle total actual fluid flow rates ranging from 100 bbl/d to 29,000 bbl/d. This amounts to a turn down ratio of about 300:1 for the High GVF Meter. Another important improvement in this design is the capability of the High GVF Meter to handle high liquid turndowns at very high gas volume fractions. The importance of these capabilities can be appreciated by the data in Table 4. To handle the 9 wells shown in this table would have required either a very large multiphase meter or multiple small meters at much higher cost than a single 2" High GVF Meter (Model 400-20). The use of the High GVF Meter provides a wide range of capabilities at lower cost.

The gas by-pass loop shown in Figure 2 can be configured as an add-on to the Multiphase Meter to enhance its capacity in production situations where the total flow rates exceed the capacity of the MPFM 300 Series Meter. The addition of the MPFM 400 loop has no effect on the measurement capabilities of the 300 Series Meter. For additional flexibility, the measurement system can be deployed in either the 300 Series or the 400 Series configuration, as the application warrants.

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4. U.S. Patent 5,099,697 and foreign counter parts, "Two and Three Phase Flow Measurements".

5. U.S. Patent 5,461,930 and foreign counterparts, "Apparatus and Methods for Measuring Two or Three Phase Fluid Flow Utilizing One or More Momentum Flow Meters and a Volumetric Flow Meter".

6 TAITEL, Y. and DUKLER, A.E., "A Model for Predicting Flow Regime Transition in Horizontal and Near Horizontal Gas-Liquid Flow", AIChE. J., 22, No. 1, pp 47-55, 1976.

7 XIAO J.J., SHOHAM, O., and J. P. BRILL, "A Comprehensive Mechanistic Model for Two Phase Flow in Pipelines", SPE Paper 20631 presented at the SPE 65th annual Meeting, New Orleans, September 23-26, (1990).

8 COLMENARES, J., PERRY, D., GUEVARA, E., and PADRON, A. , "Multiphase Flow Metering of Heavy Crude- Oil Field Evaluation", Multiphase 95, Cannes, France, June, 1995.

9. TUSS, B. and MEHDIZADEH, P., "Field Test of a High Viscosity Multiphase Meter", IPC Conference, Calgary Canada, Paper No. 629, July 1996.

TABLE 1
ACCURACY AND CAPACITY FOR A NUMBER OF COMMON 400 SERIES METERS

MPFM-401 Series	Gas Flow Rate Error	Oil Flow Rate Error	Water Flow Rate Error
MPFM-401-20	± 5% of full scale* ± 10% of gas reading	± 90 BBL/D, or ± 10% of oil flow	± 90 BBL/D, or ± 10% of water flow
MPFM-401-30	± 5% of full scale* ± 10% of gas reading	± 180 BBL/D, or ± 10% of oil flow	± 180 BBL/D, or ± 10% of water flow
MPFM-401-40	± 5% of full scale* ± 10% of gas reading	± 480 BBL/D, or ± 10% of oil flow	± 480 BBL/D, or ± 10% of water flow

*Full scale depends on the size of the 400 bypass loop.

TABLE 2
TESTING CAPABILITIES AND FLUID PROPERTIES

TEST PARAMETERS	CAPABILITIES	FLUID PROPERTIES	
		Gas Specific Gravity	0.699
Pressure	150 psig	H_2S	3 PPM
Temperature	Approx. 80°F - 120°F	CO_2	2% (mol percent)
Gas Flow	0-2MMSCFPD (2" Flowline) - 0 - 100 ft/sec Superficial Gas Velocity	Condensate	46.5° API 0.7949 sp. gr. 2.1 cSt @ 100° F
Condensate/Crude Oil/ Produced Water	0-7000 BFPD (2" Flowline) - 0-100% Water Cut 0-21 ft/sec Superficial Liquid Velocity	Produced Water	1.0535 sp. gr.

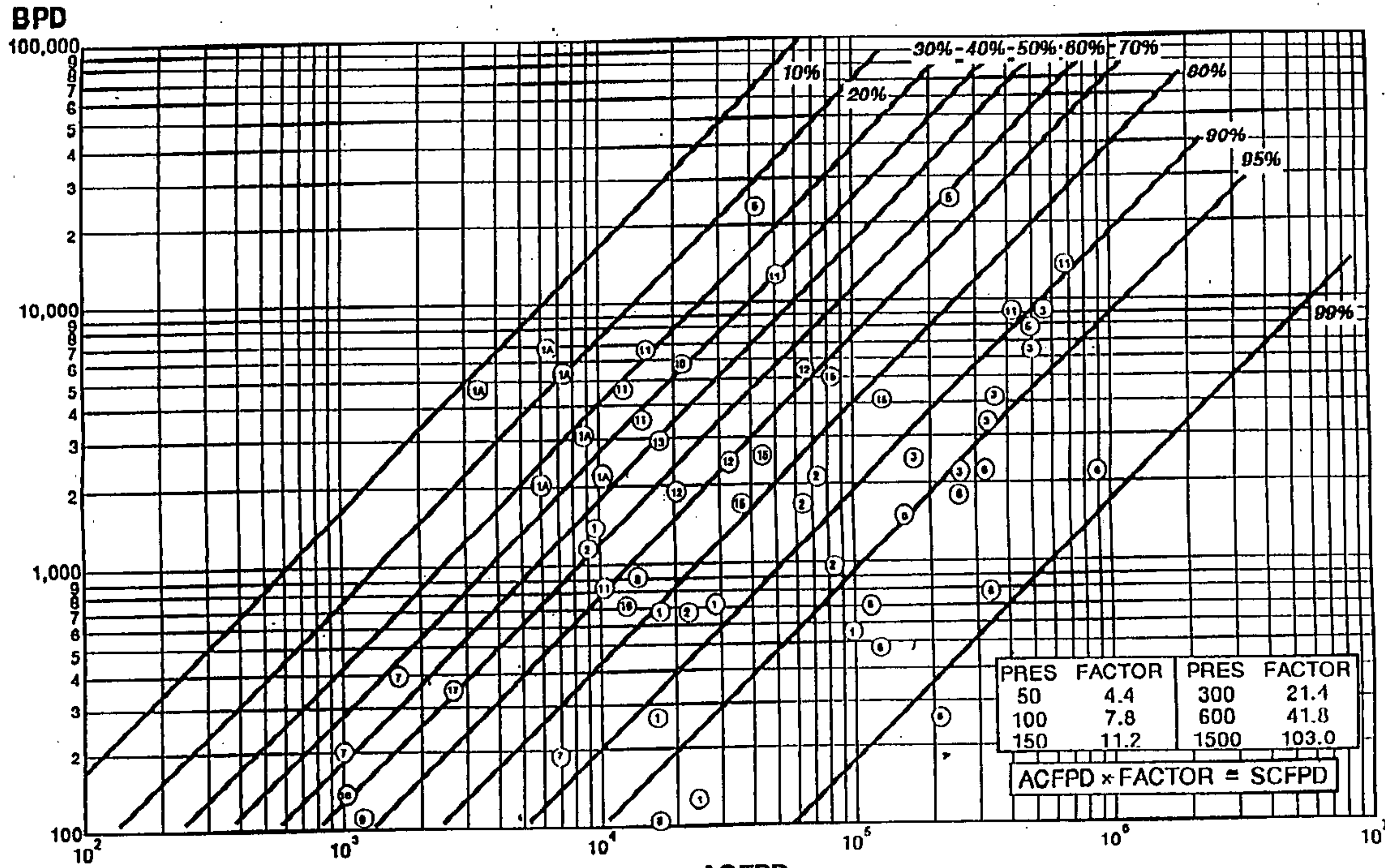
TABLE 3
WELL FLOW CONDITIONS REPRESENTED BY POINTS 1 TO 4 IN FIGURE 5

TEST CONDITION	WELL FLOW CONDITIONS			
POINT IN FIG. 5	LIQUID RATE BBL/D	OIL RATE BBL/D	WATER CUT %	GAS RATE MMSCF/D
1	1190	595	50	10
2	396	316	25	20
3	198	50	75	10
4	198	20	90	10

TABLE 4
WELLS SHOWN IN FIGURE 13
TESTED BY THE MPFM-401-20
WITHIN THE ACCURACIES SHOWN IN TABLE 1

WELL	PRESSURE	OIL	WATER	GAS	GAS	GOR	GVF	TOTAL FLOW
NAME	PSI	BPD	BPD	MSCF/D	MACF/D	SCF/BO	%	BPD
A1	600	680	350	340	10	500	63	2775
A2	500	680	350	1,360	39	2,000	87	8,010
A3	600	680	350	4,700	137	7,000	96	25,459
A4	600	680	350	8,160	235	12,000	98	42,909
A5	600	680	350	23,800	684	35,000	99	123,177
A6	600	680	350	680	20	1,000	77	4,520
A7	400	680	350	680	29	1,000	84	6,265
A8	200	680	350	680	59	1,000	91	11,500
A9	75	680	350	680	156	1,000	96	28,949

FIGURE 1
WELL CHARACTERISTICS (GAS TO LIQUID RATIOS) FROM DIFFERENT PRODUCTION REGIONS AROUND THE WORLD



PRES	FACTOR	PRES	FACTOR
50	4.4	300	21.4
100	7.8	600	41.8
150	11.2	1500	103.0

$$BPD_{LIQ} = \frac{(1\text{-}GVF)}{GVF * 5.614} \; ACFPD$$

GVF = Actual Gas Volume Fract.
ACFPD = Actual Cubic Feet Per Day

FIGURE 2
SCHEMATIC OF THE MPFM-400 SERIES METER

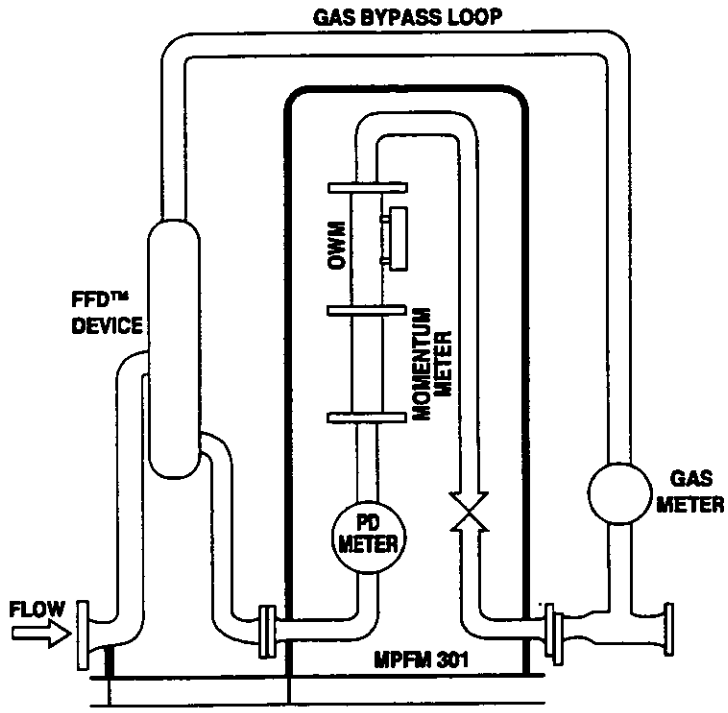


FIGURE 3
MULTIPHASE FLOW TEST FACILITY

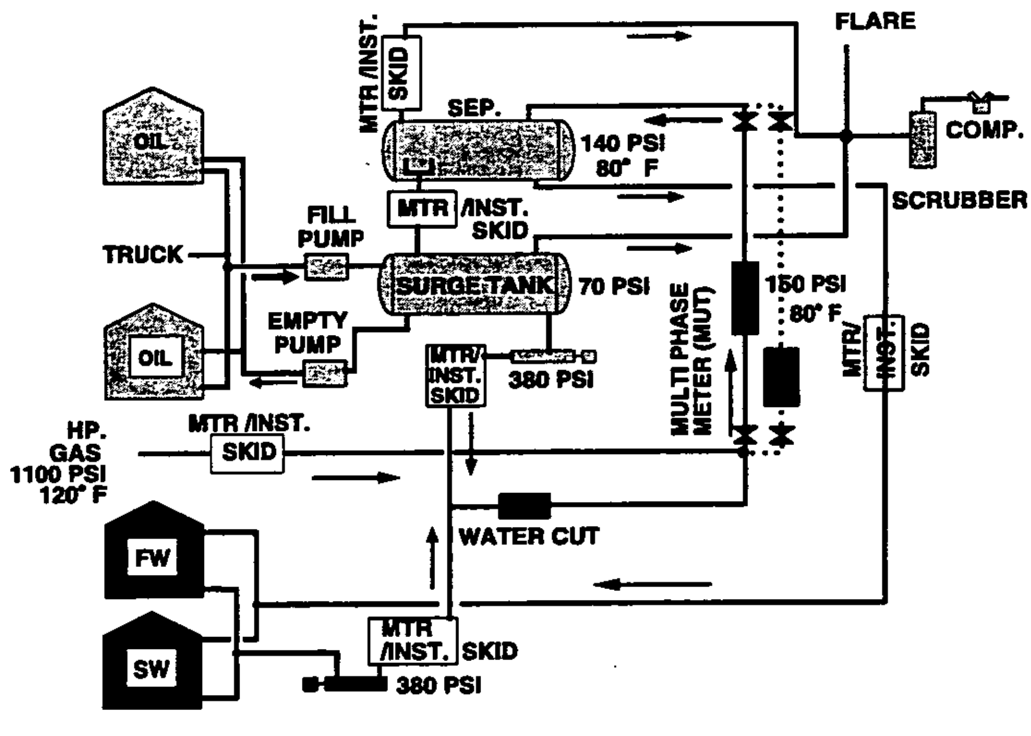


FIGURE 4
2" MPFM-400 SERIES METER SIMILAR TO THE ONE USED IN THE FIELD TESTS

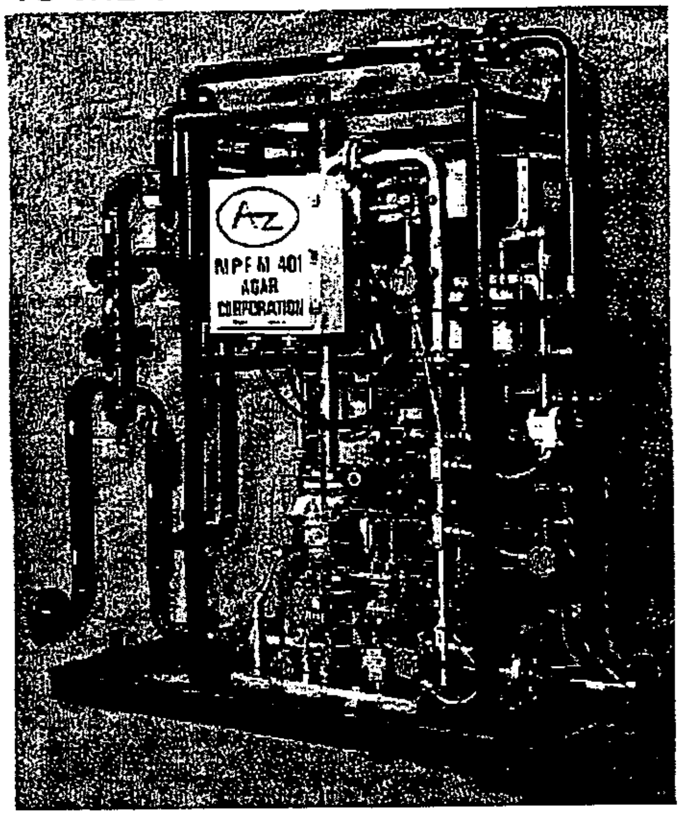


FIGURE 5
TEST MATRIX FOR AGAR MPFM-401 USED AT CONOCO FACILITY

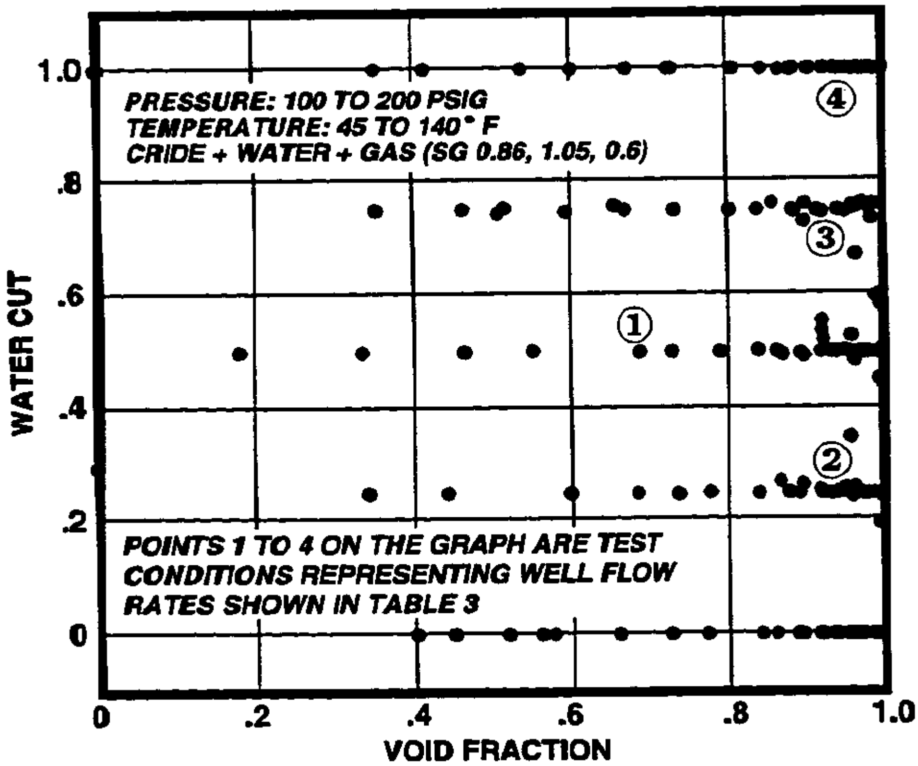


FIGURE 6
LIQUID VERSUS GAS SUPERFICIAL VELOCITY

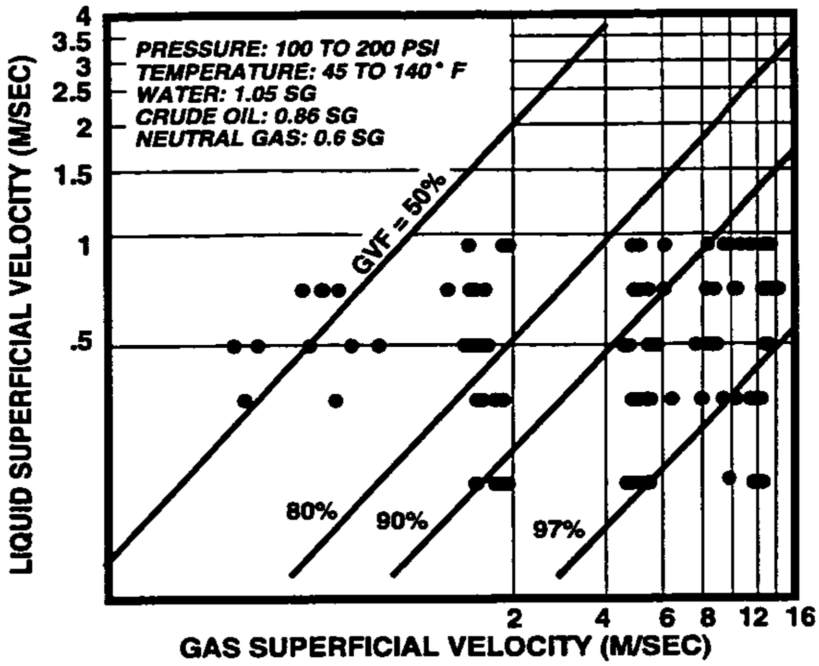


FIGURE 7
AGAR MPFM-401 VERSUS CONOCO LOOP OIL FLOW RATE

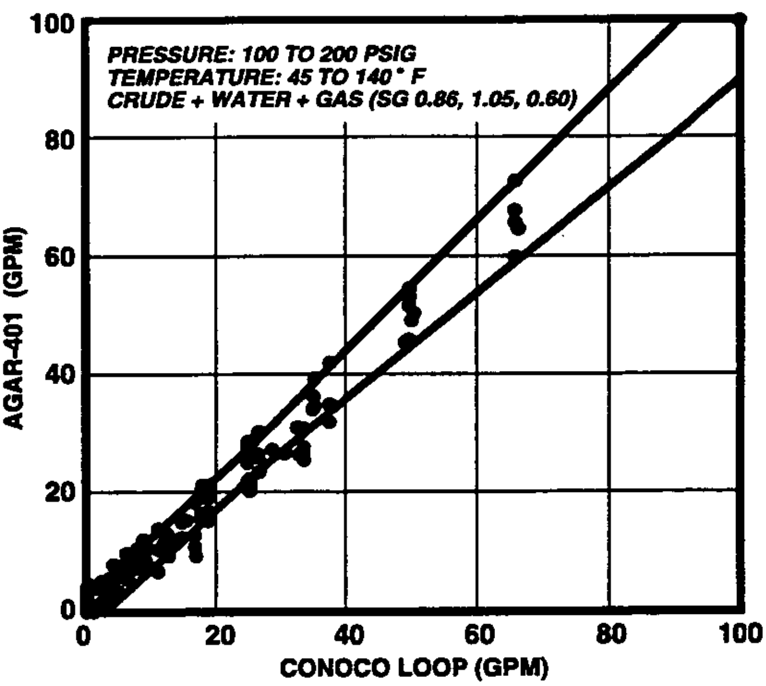


FIGURE 8
AGAR MPFM-401 VERSUS CONOCO LOOP WATER FLOW RATE

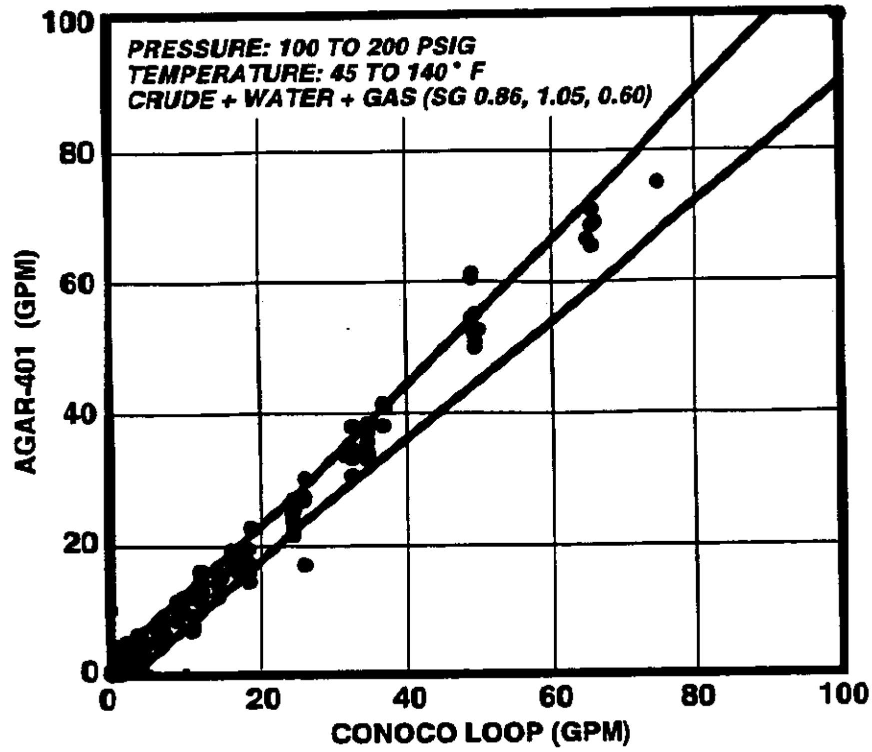


FIGURE 9
AGAR MPFM-401 VERSUS CONOCO LOOP GAS FLOW RATE

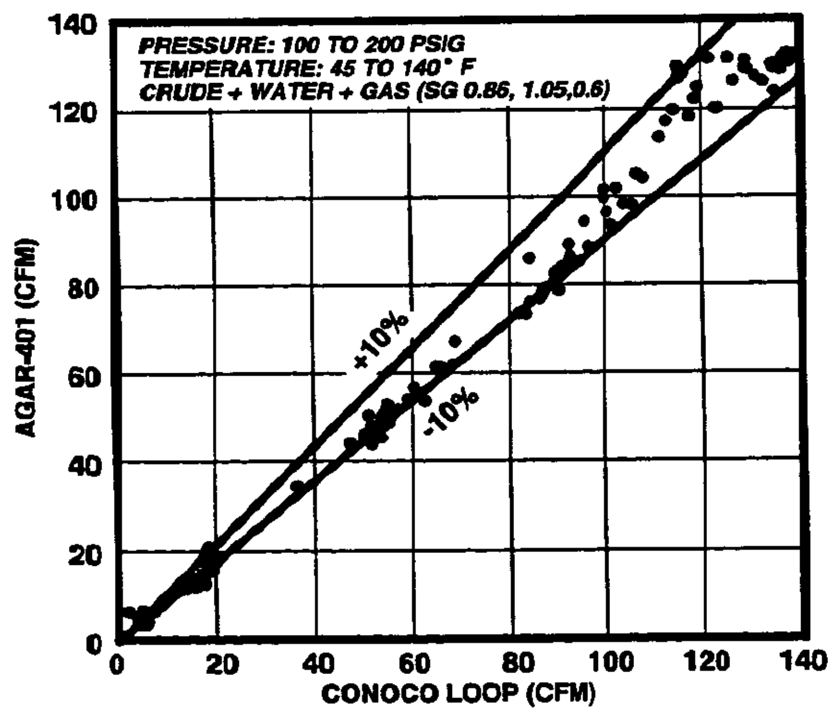


FIGURE 10
AGAR MPFM-401 VERSUS CONOCO LOOP LIQUID FLOW RATE

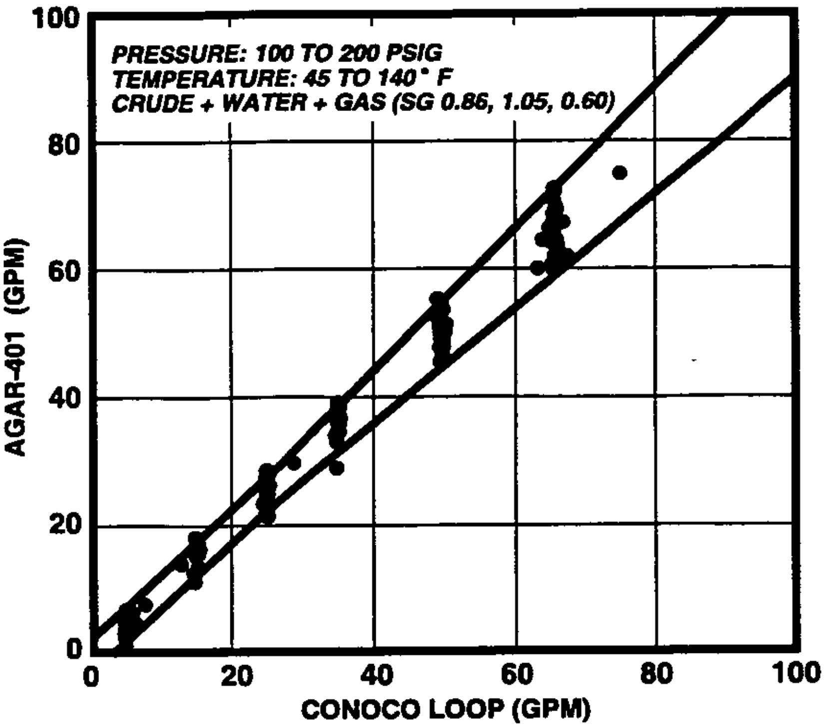


FIGURE 11
AGAR MPFM-401 VERSUS CONOCO LOOP TOTAL FLOW RATE

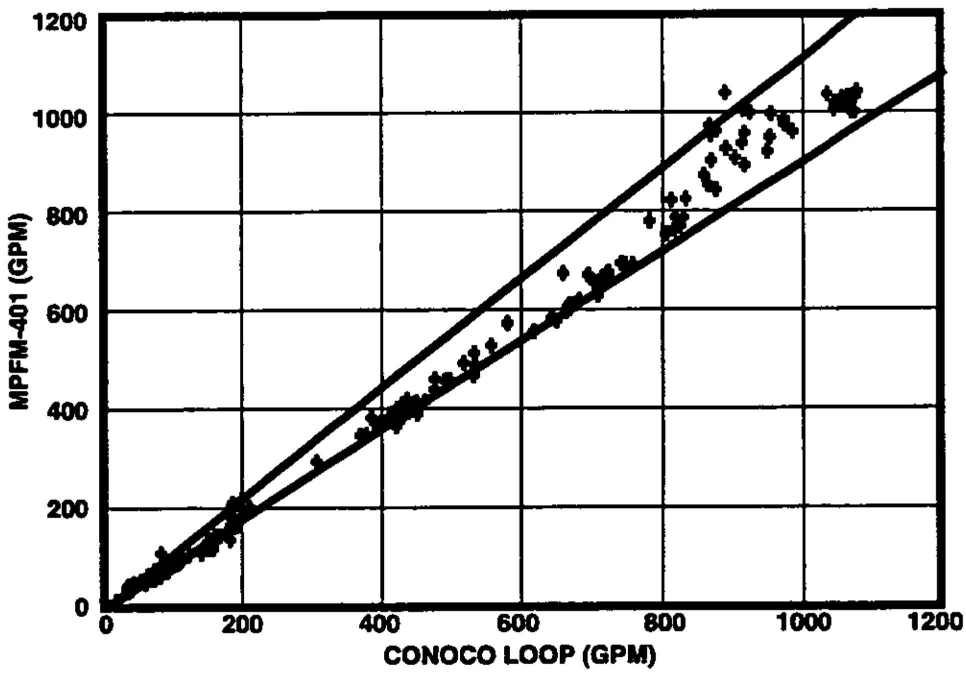


FIGURE 12
GAS AND LIQUID CAPACITIES
MPFM-400 SERIES METER

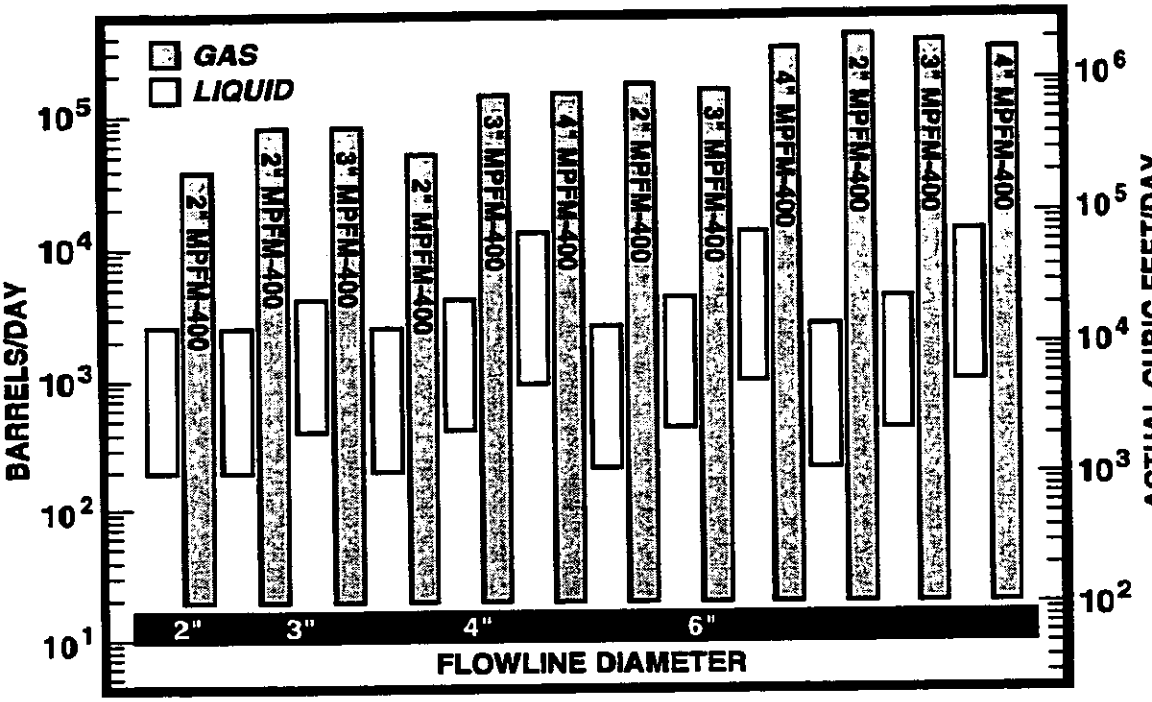


FIGURE 13
PERFORMANCE ENVELOPE FOR MPFM-401-20
4" - 6" LOOP CONNECTED TO 6" FLOWLINE AT 600 PSIG
(Points 1-9 in the Graph refer to the well flow rates in Table 4)