WELLHEAD METERING OF GAS/OIL/WATER PRODUCTION STREAMS

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INTRODUCTION

Several prototype instruments for metering gas, oil and water production rates at the wellhead and for monitoring multiphase flow in pipes have been developed by Texaco at the Houston Research Center and by Rogaland Research Institute near Stavanger, Norway, and the Institute for Energy Technology near Kjeller, Norway, in collaboration with and under the support of Texaco. The economic advantages of wellhead metering--especially on offshore platforms and at subsea completions--and of improving multiphase flow transport and handling systems are the driving forces for these instrument developments. In this paper, design details, and laboratory and field tests results of wellhead metering instruments intended to acquire well test data are presented.

The design measurement requirements of these prototype wellhead production meters for acquiring well test data are to determine gas and liquid production rates to within ±5% of full scale, and percent water (% w) to within ±2% w for 0 to 10% w, to within ±3% w for 10 to 20% w, and to within ±5% w for 20 to 100% w. (Percent water is defined to be one hundred times the water volumetric fraction of the liquid.) The range of the meter should (1) have a turndown of at least eight to one for the total (gas plus oil plus water) volume flow rate at measuring conditions, (2) span the anticipated gas/liquid ratios at measuring conditions, and (3) span anticipated instantaneous water-cuts--which usually range from 0% w to several times the anticipated maximum daily average water-cut. (In many installations instantaneous water-cuts will range well above 40% w and measurements from 0 to 100% w will be required.) These metering systems--especially those for subsea use--should have no moving parts and no regions where solids accumulate. While the size of the meter can be quite small, appropriate entrance and exit piping is necessary in order to obtain the desired accuracies. Depending on the type of multiphase flow meter, the entrance and exit lengths vary from those of a single phase flow meter--i.e., entrance length of 20 pipe diameters and exit length of 10 pipe diameters--to much greater lengths. We envision the shortest system (meter, and entrance and exit piping) designed to handle 18,000 BBL/D and comparable volumes of gas to be approximately four meters long.

The instruments under development in this program are of two types:

1. flow-nondisturbing instruments--non-intrusive instruments of the same internal diameter as the production line (for monitoring as well as metering multiphase flow), and
2. flow-disturbing instruments--intrusive and non-intrusive wellhead meters with internal geometries different from that of the production line.

At present neither type has any moving parts or solids-accumulation points. Some details of the design of these instruments and results of laboratory and field tests are presented below..

FLOW-NONDISTURBING INSTRUMENTS

The sensors of these instruments are either incorporated in a non-intrusive spool piece having the same internal diameter as the entrance and exit piping, or are "clamped-on" to the outside of the production pipeline. Obviously such instruments have the very significant advantage of introducing no changes in the production flow. They are consequently ideal for monitoring multiphase flow in pipelines (for design data--such as holdup) and for metering multiphase flow. However, metering with these flow-nondisturbing instruments requires a precise understanding of the details of multiphase flow in pipes. The instruments used to obtain the required information are discussed briefly below. Enhanced versions of these instruments have metered oil/gas flow successfully and are now metering oil/water/ gas flows.

One of these instruments measures the dielectric distribution within the pipe with sensors external to the flow. The first such system was developed by Mattar and Gregory.[1] The current system developed by Rogaland Research Institute and Texaco has an axial spacial resolution on the order of one millimeter, determines parameters describing the dielectric distribution within a pipe cross section, measures the velocity of propagation of dielectric transients, and has a pressure rating of 3000 psi. Typical time traces for two sensors of the system are shown in Figure 1. The vertical axis is a function of hold-up with high readings corresponding to high hold-ups. The horizontal axis is time in seconds. These traces were acquired while slug flow was present in the pipe. The upstream sensor output is the upper trace and the downstream sensor output is the lower trace. As is typical for slug flow the sensors alternatively "see" gas pockets -- for example, from 8.0 to 8.8 seconds on the upstream sensor -- and liquid plugs -- for example, from 8.8 to 9.4 seconds on the upstream sensor. Small bubbles in the plug part of the slugs can be seen and correlated between the two traces (for example, the bubble in the liquid plug in the upstream trace at 8.9 seconds corresponds to the bubble in the downstream trace at 9.1 seconds). Furthermore, it is clear that the gas pockets are moving at a higher velocity than the small bubbles in the liquid plugs. Similarly the origin or seed of pocket front disturbances (at 7.6 and 9.8 seconds) on the downstream trace can be seen (at 7.5 and 9.7 seconds) on the upstream time trace. A much finer time scale than shown here is required to exploit the full resolution of the instrument.

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1 G. A. Gregory and L. Mattar, "An In-Situ Volume Fraction Sensor for Two-Phase Flows of Non-Electrolytes," The Journal of Canadian Petroleum Technology, April-June 1973, Montreal, Canada.

Another flow-nondisturbing instrument, the Fast Volume Weight Meter, measures the fluids distribution within the pipe via nuclear techniques. Developed by the Institute for Energy Technology and Texaco, this instrument measures the pipe-cross-sectional liquid fraction or hold-up, determines parameters describing the liquid distribution within the pipe cross section, measures the velocity of propagation of hold-up transients, mounts on the outside of the production line and is "portable." Counting rates as high as 800,000 counts per second are used to determine the hold-up. Time traces from this instrument are qualitatively similar to those of the dielectric based system aside from variations due to nuclear statistics. This instrument -- because of its unique capability to measure cross sectional liquid fraction or hold-up -- is being used by SINTEF at the Two Phase Flow Laboratory near Trondheim, and has been ordered by the Harwell Laboratories, Atomic Energy Research Establishment for their multiclient Pipeline Instrumentation Project.

Metering models are being developed for all flow patterns with these systems. Tests performed at near atmospheric and high pressures yield very similar metering results. Much of the testing has been carried out at Texaco's Houston Research Center. This facility has low and high pressure test loops. The high pressure loop operates at pressures up to 500 psi with oil, water and nitrogen gas. A test hole over 300 feet deep is used to simulate wellhead flow. The fluids from separate gas and liquid lines are merged at the bottom of the hole; the resulting multiphase mixture flows to the surface in 2-, 3- or 4-inch pipe and is used as a "wellhead production stream" to test metering systems. Oil and water flow rates up to 7,000 BBL/D and gas rates high enough to produce annular flow in vertical 4-inch pipe are available. Some test results obtained in July 1984, at Texaco's Houston Research Center are shown in Figures 2 and 3.

Figure 2 displays the percent-of-value error of the metered gas flow rates as a function of gas flow rate expressed in actual cubic feet per minute on the horizontal axis and as a function of liquid flow rate expressed in U.S. gallons per minute on the vertical axis.

percent-of-value error ≡ 100 * (metered - actual) / actual

The metered gas flow rates are in general within three percent of the actual values. The error values are significantly smaller when expressed in terms of percent-of-full-scale error.

percent-of-full-scale error ≡ 100 * (metered - actual) / (full scale)

All the error values are well within the accuracy requirements of ± 5 percent-of-full-scale.

Figure 3 displays the percent-of-value error of the metered liquid flow rates as a function of gas and liquid flow rates. All the error values are well within the accuracy requirements of ±5 percent-of-full-scale except possibly the value at 500 $feet^3$/hour and 73 gallons/minute.

The range of the instrument used to acquire the data in Figures 2 and 3 has been extended, and the instrument has been enhanced to also measure water-cut. Figure 4 displays the percent-water error of the metered water-cut as a function of gas and liquid flow rates for an actual water-cut of 0% w.

percent-water error = [(metered % w) - (actual % w)]

The values are all within ±1% w and satisfy the accuracy requirements of ±2% w for this range of water cuts.

Figure 5 displays the percent water error of the metered water cut as a function of gas and liquid flow rates for actual water-cuts of approximately 10% w. The results are within the accuracy requirements of ±2% to ±3% w for this range of water cuts.

FLOW-DISTURBING INSTRUMENTS

While these systems do disturb the production stream flow, they do so in ways that are intended to

1. interfere minimally with production -- i.e., without introducing high pressure drops or solids-accumulation regions, and
2. provide accurate reliable metering.

These systems are intended for platform and subsea use. This is the type of metering system Texaco currently plans to install subsea first -- probably in the North Sea. Full details of these instruments are not available for public discussion at this time. One component of some of these systems is a microwave-based water-cut monitor which has been developed by Texaco under partial support by ARAMCO. Results of the most recent offshore test of this water-cut monitor are presented below.

This microwave-based system, like capacitance probes, determines water cut by measuring the fluid dielectric constant. However, the microwave system accurately measures water cuts from 0 to 100% w for water-continuous and oil-continuous systems and does not suffer the problems associated with capacitance probe measurements on water continuous systems. This water-cut monitor system operates on the full oil/water/gas production stream to measure the water-cut of the produced liquids.

Results of the most recent field test are shown in Table 1. Flow rates of the tested wells are shown in BBL/D. The time duration of a well test was typically eight hours. The test pressures ranged from 300 to 400 psi, and GOR's ranged from 300 to 400. The agreement is probably to within the accuracy of the test separator system, and is well within well test accuracy requirements. The displayed water cuts are the test-duration averaged water cuts; instantaneous water cuts varied from 0 to well over 80% w. This microwave test system was designed to handle up to 18,000 BBL/D and comparable volumes of gas, with a pressure drop of at most 2 psi.

SUMMARY

Prototype instruments have proved adequate to measure flow rates to well test accuracies. Texaco's first subsea metering system may be installed as early as 1987.

TABLE 1

COMPARISON OF TEST SEPARATOR AND MICROWAVE WATER-CUT MONITOR

FLOW RATE#	PERCENT-WATER MEASUREMENTS	
	TEST SEPARATOR	MICROWAVE MONITOR
6,100	48.3	46.8
7,670	30.2	30.4
6,950	17.1	18.2
5,780	1.9	3.1
7,500	29.2	26.1
10,710	0.1	0.1
6,450	0.0	0.1
11,260	1.8	0.7
6,640	0.6	0.9
5,590	0.0	0.0
11,320	42.1	40.2

Flow rate in BBL/D (barrels (42 U.S. gallons) of liquid per day.

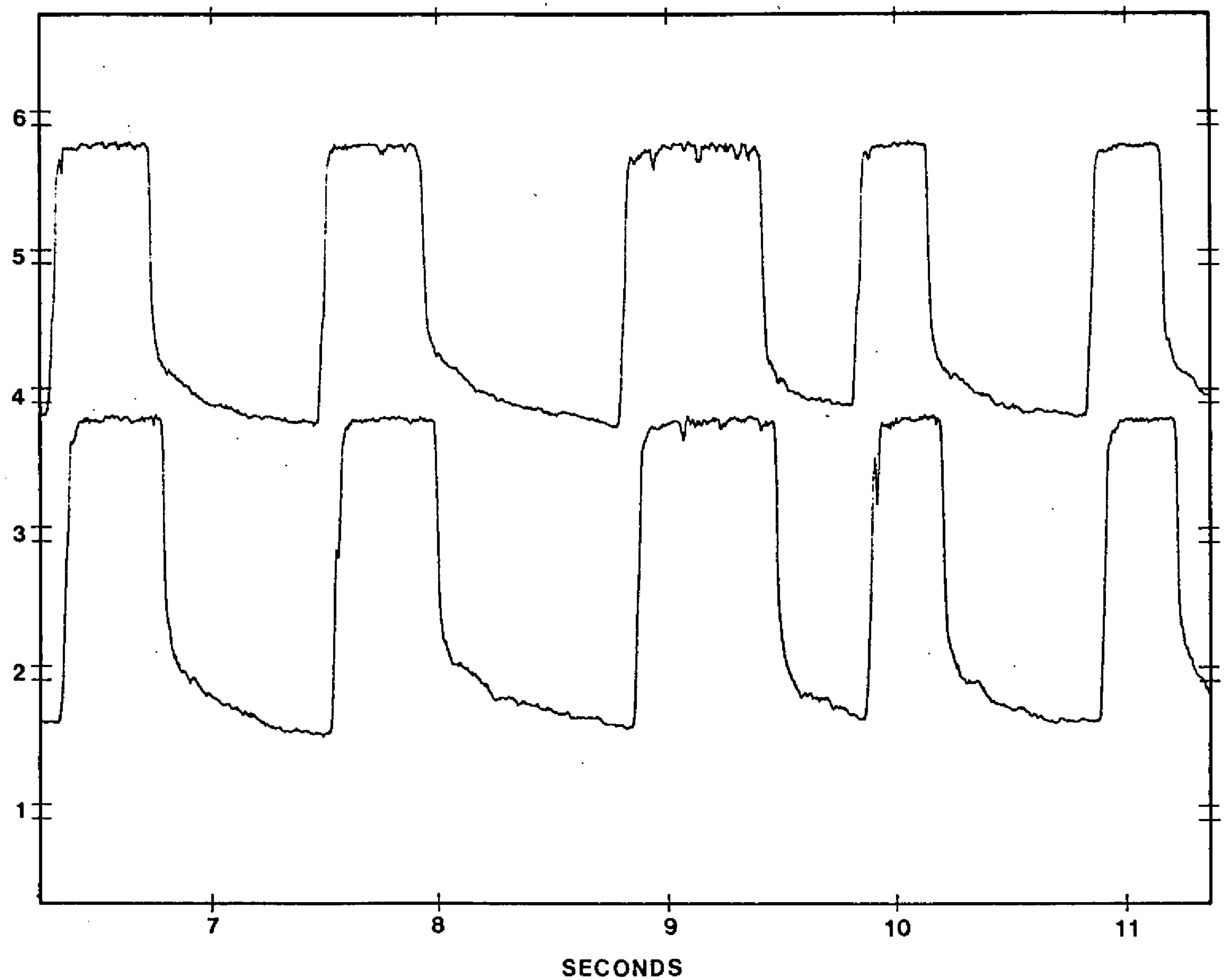

FIGURE 1   SLUG FLOW TRACES

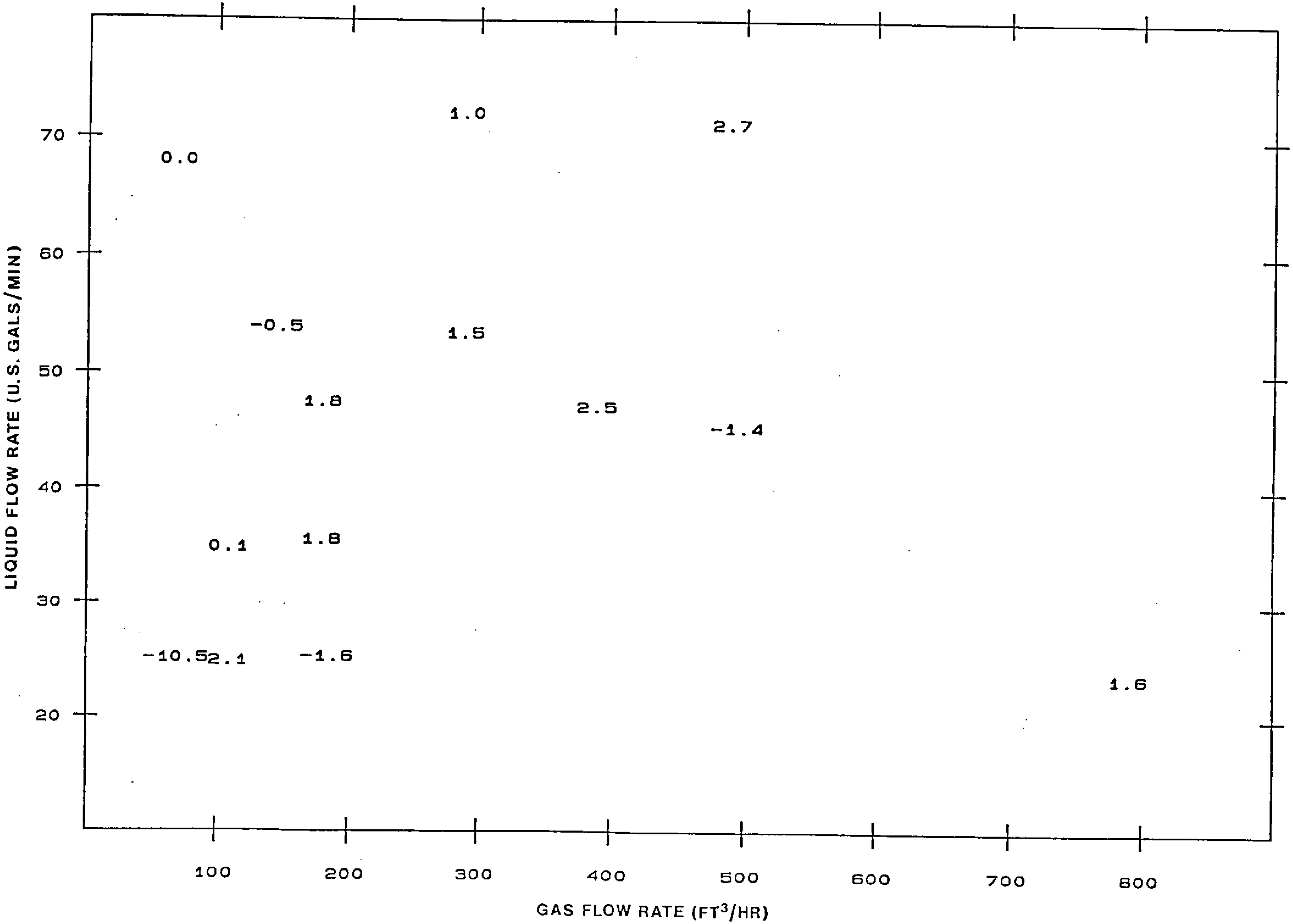

FIGURE 2 GAS RATE PERCENT-OF-VALUE ERROR

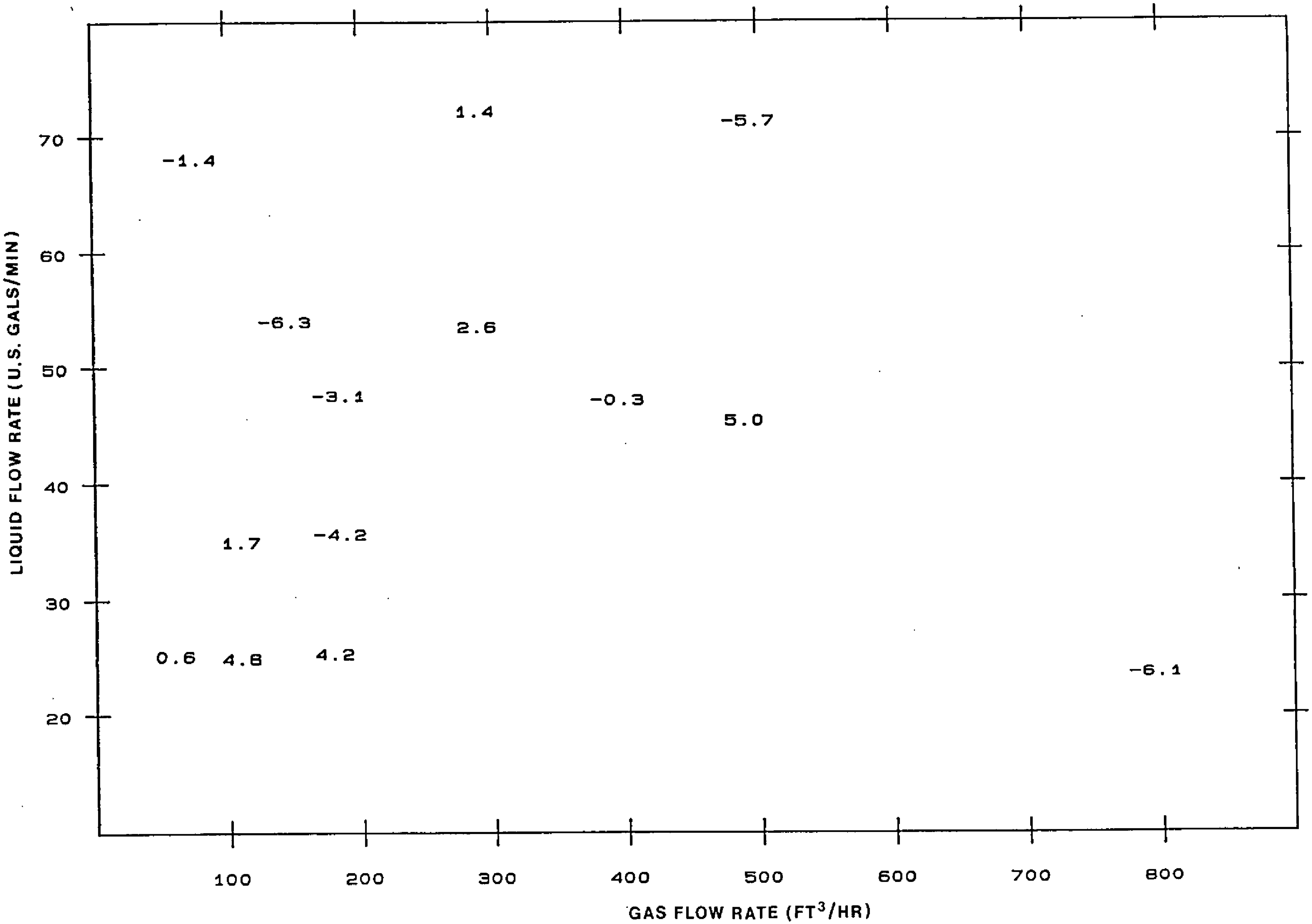

FIGURE 3 LIQUID RATE PERCENT-OF-VALUE ERROR

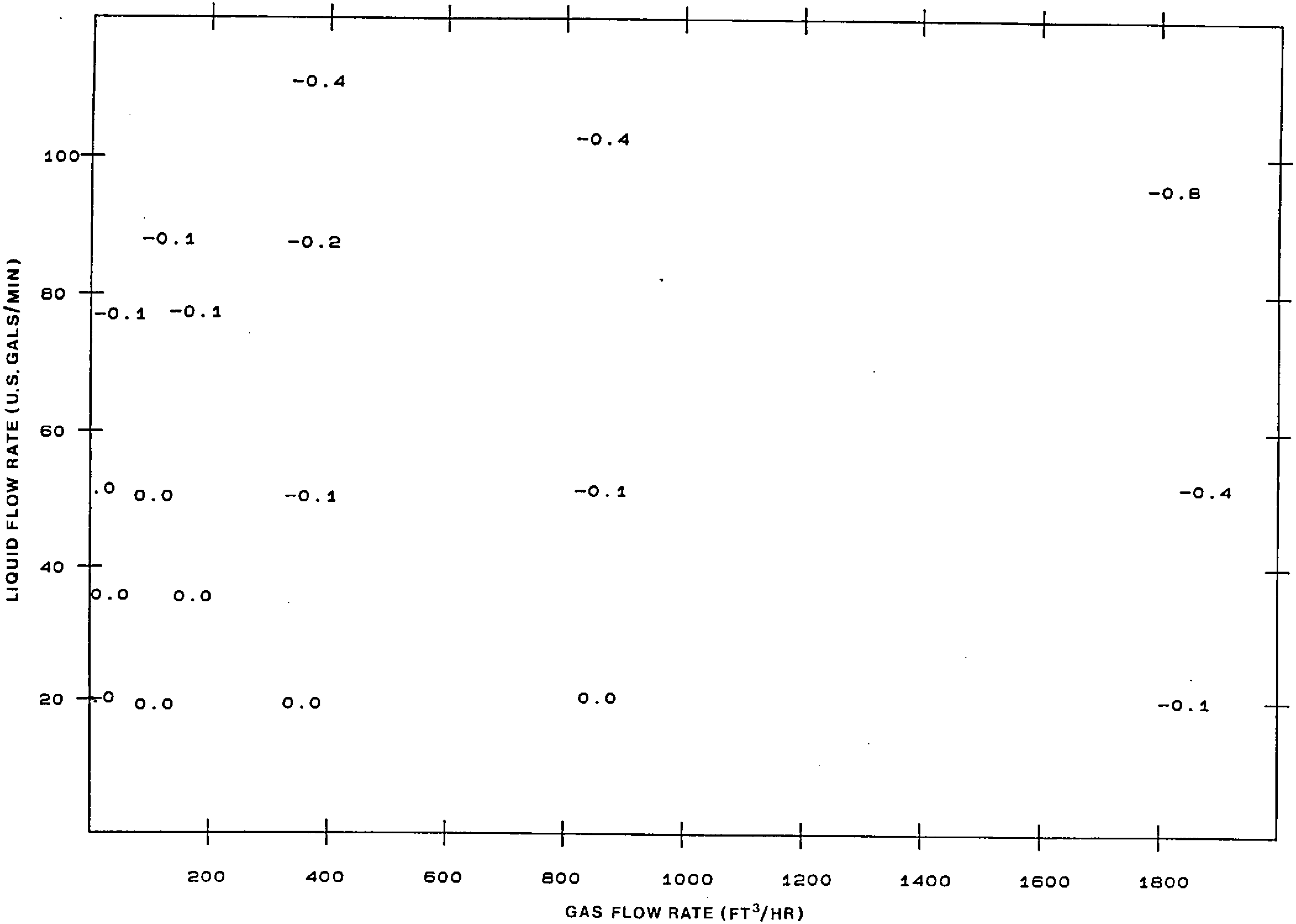

FIGURE 4 PERCENT-WATER ERROR (WATER-CUT ~ 0.0)

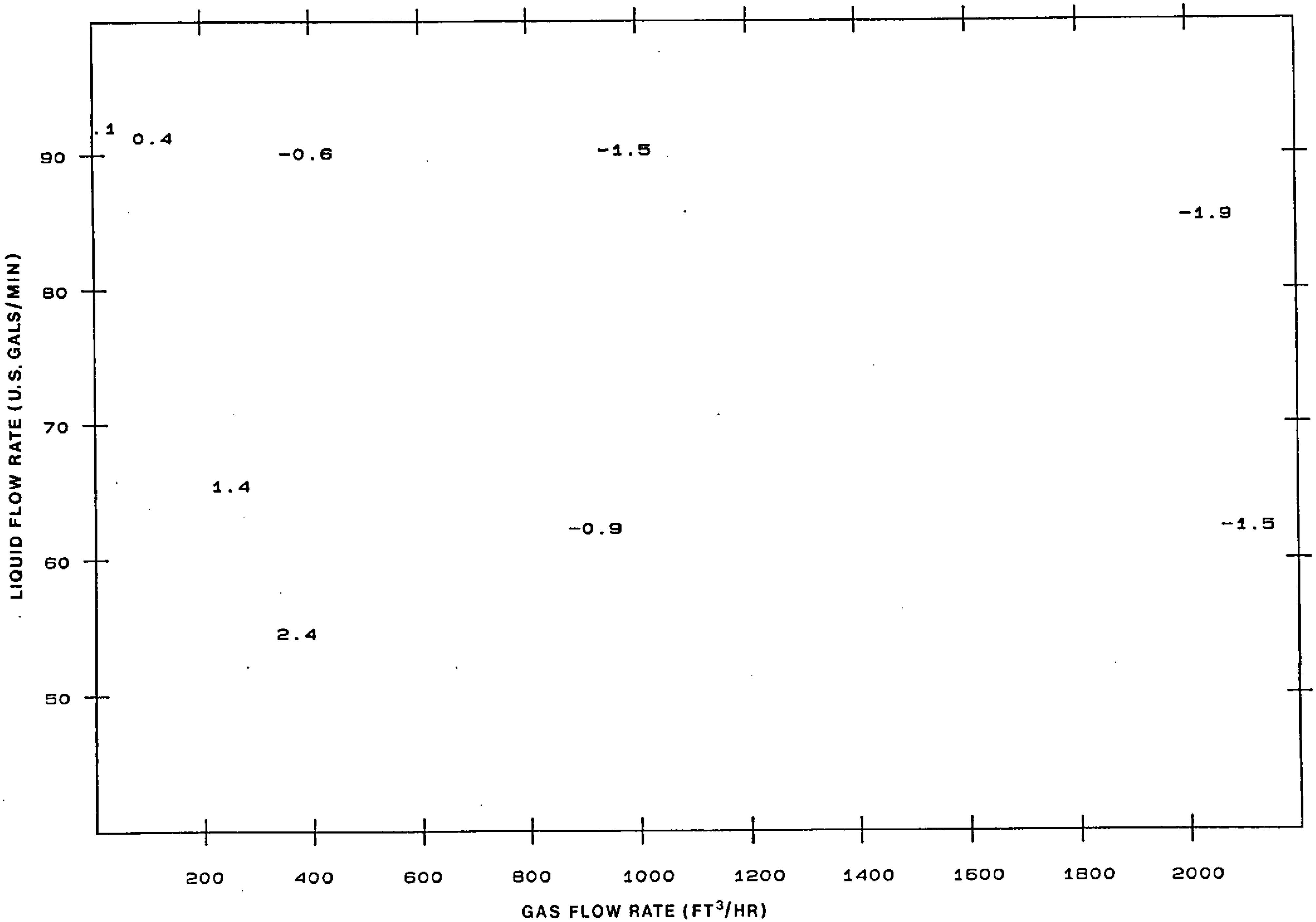

FIGURE 5 PERCENT – WATER ERROR (WATER – CUT ~ 0.10)

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.