TRANSIENT PRESSURE INTERPRETATION IN A DEEP DELAWARE BASIN GAS WELL

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ABSTRACT

As the search for new gas supplies intensifies, deeper reservoirs are being investigated. The following describes the design, testing, and difficulties encountered in transient pressure analysis in a high pressure, low permeability gas well. The conclusions drawn from the test will also be discussed. Transient pressure testing was selected as the most timely method to describe the reservoir. The pseudo-pressure technique was applied to the data obtained.

The subject well, Emma Lou Gas Unit 1, Well No. 1, was completed from 22,156 ft to 22,240 ft in the Puckett West Bend Field, Pecos County, Texas. The initial reservoir pressure was greater than 18,000 psi, and the reservoir temperature was in excess of 360^{o} F. Due to the pressure and temperature in this well being beyond any empirical relationships, the compressibility and viscosity data were obtained from the Peng Robinson Equation of State. All test data was gathered at the wellhead, and the bottom-hole conditions were calculated from the Cullender and Smith Sandface Pressure Method. Due to a rapid decline in pressure, a multi-rate test was initiated. No conclusive evidence of a reservoir boundary was seen during the testing. However, due to the low kh and deliverability, additional drilling was not undertaken.

Even though the test was performed in a limited time and without laboratory analysis of fluid and formation properties, well performance to date has supported the reservoir description from the drawdown and multi-rate tests.

INTRODUCTION

Deep, high pressured gas wells are being drilled to meet the ever increasing demand for gas. A reservoir engineer must evaluate new wells for deliverability and reserves. This information aids management in making decisions to continue exploration. Transient pressure testing is often not only the best tool for these evaluations, but the only tool. While transient pressure analysis may appear difficult, it can be employed effectively by operations personnel.

To follow is a description of the transient pressure techniques applied to the Emma Lou Gas Unit 1, Well No. 1 and the results from this test.

PROBLEM DESCRIPTION

A continuous drilling clause in the Unit Agreement required drilling to commence within 180 days upon completion of a well. To evaluate the feasibility of drilling additional wells, an economic evaluation had to be made on the subject well. Needed for this model would be a reservoir description. Included must be a deliverability and a reservoir size. Transient pressure analysis was selected as the only available means to gather this data.

WELL LOCATION AND DESCRIPTION

The Emma Lou Gas Unit 1, Well No. 1 is located south of Fort Stockton, in Pecos County, Texas (Fig. No. 1). The well was spudded November 27, 1976 and was completed in the Puckett West Bend Field.

The Emma Lou Gas Unit 1, Well No. 1 was drilled to a total depth of 23,198 ft and plugged back to 22,240 ft. The casing string consists of 7 3/4 in. from 22,209 ft to surface. There is 6 1/2 in. open hole from 22,240 ft to 22,209 ft. The well was perforated in four intervals from 22,156 ft to 22,196 ft with 2-0.46 in. J.H.P.F. (24 holes total). The tubing string consists of 10,693 ft of 2 7/8 in. tubing and 7,796 ft of 3 1/2 in. Two packers were set, one at 18,500 ft and one at 18,490 ft (Fig. No. 2).

The reservoir parameters for this well were determined by direct measurement and empirical relationships. A porosity log across the entire pay was not obtained. Porosity from the open hole log was correlated to the drill time log. The net thickness was estimated to be 50 ft from the drilling time log. Porosity was estimated to be 4%. Water saturation was estimated to be 20%. The measured gas gravity was .603. The original bottom hole pressure was calculated to be 18,500 psi, based on the weight of the drilling fluid. The bottom hole temperature was measured in excess of 360° F. The Peng Robinson Equation of State was used to derive the compressibility and viscosity values for this well. Compressibility was 37 x 10^{-6} $psia^{-1}$ and the viscosity was 0.0429 cp. The permeability was estimated to .15 md. This value was based on a previous buildup test where $kh/\mu = 173.6$.

THEORY

The pressure drawdown test is favorable for wells that have been shut in a sufficient length of time to stabilize the drainage area. The well continues to produce during the test, while the production rate is held constant. Holding the rate constant is the critical factor to consider in designing this test.

The constant flow rate introduces a pressure wave or pulse at the sandface. This pulse will experience three separate flow periods; transient, late transient, and pseudosteady state. During transient flow, the pulse will not reach a boundary. Therefore, the pressure behavior is not affected by a boundary. During late transient the pulse is striking a boundary and interferes with returning pulses. In pseudosteady state flow, the transient has reached a boundary and reservoir depletion begins. The distance to this boundary can be calculated and the gas in place estimated. The pressure throughout the reservoir is changing at the same rate as a linear function of time during pseudosteady state.

The Cullender and Smith Method is recognized as a reliable technique for the calculation of static bottom hole pressures from wellhead observations. The method avoids the use of simplifying assumptions for temperature and compressibility factors. It is applicable to both shallow and deep wells, and may be adapted to computer programming. Because of the depth, and a history of unstable bottom hole conditions, the pressure data for this well was taken at the surface. The Cullender and Smith technique was then applied to this application in the form of a computer program.

Correlations between viscosity, deviation factor and pressure had to be determined. Gas analysis had been performed and the results are in Fig. No. 3. While the gas analysis indicates a fluid should be easily modeled with the simple correlations, the difficulty arises with the high reservoir pressure and temperature. The best available correlation was the Peng Robinson Equation of State.

During the course of a drawdown the bottom hole pressure could range from 18,000 psi to less than 3,000 psi. The temperature from the reservoir to surface also had a large variance (340° F to 70° F). Figures No. 4 and 5 define the relationship between pressure and viscosity and pressure and gas deviation factor respectively. The p^2 methods assume a constant value for both the viscosity and deviation factor throughout the test and are defined by the equation:

$$\tilde{p} = \left[\frac{p_i^2 + p_{wf}^2}{2}\right]^{1/2} \quad (1)$$

This discrepancy was unacceptable for this high pressure gas well.

The method applied to this test was the real gas pseudo pressure, m(p). This pressure group is mathematically expressed as

$$m(p) = 2 \int_{p_b}^{p} \frac{p}{\mu z}\, dp, \ \text{psia}^2/\text{cp} \quad (2)$$

With this equation, an isothermal system is assumed. Fig No. 6 is a plot of $p/\mu z$ versus p for the Emma Lou #1. The m(p) function is determined by calculating the area under the $p/\mu z$ curve from an arbitrary, low base pressure, p_b, to the desired pressure. While this may be performed by hand, computer assistance will enhance the process. The relationship between m(p) and pressure is graphed in Fig. No. 7. From the plot of m(p) versus time, the slope is measured to determine the permeability.

TEST DESIGN

Preliminary calculations were made prior to beginning a drawdown test. The size of the reservoir was set equal to the minimum volume of reserves necessary to yield an economic drilling proposal. The aforementioned reservoir values were applied to determine the amount of time necessary to verify the reservoir contained the minimum volume of gas.

The calculation required for a single well in radial flow is as follows:

$$t^* = \frac{380\, A\, \phi\, \mu\, c_t}{k} \quad (3)$$

Where A = acres, ϕ = porosity, μ = viscosity, c_t = total compressibility, and k = permeability. The t* is the time required for a pressure transient to reach pseudo-steady state. In this case, the t* would be the number of days the well would have to flow with no evidence of a boundary. Applying the data from Emma Lou No. 1, the calculation yields 47 days minimum. If the well did not remain in transient flow through the 47 day interval, the reservoir would be too limited for further development.

DRAWDOWN TEST

The objective of this test was to determine if the transient flow time would end indicating an insufficient reservoir. A plot of the real gas pseudo-pressure, m(p), versus the log of the producing time t should yield a straight line during transient flow. The slope of the straight line is:

$$m = -\frac{1637\ qT}{kh} \qquad (4)$$

Therefore,

$$kh = -\frac{1637\ qT}{m} \qquad (5)$$

The subject well had been producing 5 days prior to initiating the test. The well had been flowing on a reduced choke to assist in water load recovery. Based on a kh value from a previous test, the initial rate of 5.8 mmcfpd was chosen. The rate was held constant by making adjustments with the choke.

The surface tubing pressure, production rate, and choke size were recorded on an hourly basis. The surface pressure gauge was found not to be sensitive enough, and therefore, a dead weight tester was substituted.

The well flowed at a rate of 5.8 mmscfpd for only 15 days. During this time interval the tubing pressure declined 3,160 psi to 1,140 psi. The original estimate of kh was too high, resulting in a larger pressure drop than anticipated. The kh was calculated from this initial flow period to be 2.49 md-ft (Fig. No. 8). The permeability was .048 md from:

$$k = -\frac{1637\ qT}{mh} \qquad (6)$$

where q = 5.8 mmscfpd, T = 800^{0} R, m = -30.4×10^{8} $psia^2$/cp/cycle.

MULTIPLE-RATE TEST

Due to this large pressure decline, the drawdown test could not be sustained. The flow rate was reduced, thereby initiating a multi-rate test. A multi-rate test consists of variable rates during the test. In this case a two rate test became necessary. The rate decreased which caused a new pressure response. Wellbore storage prevents the rate from changing instantaneously. During a multi-rate test the production continues uninterrupted and yet values for permeability and skin can be determined.

The interpretation of the pressure data with the addition of a pulse, requires the principle of superposition, which in equation form is:

$$m(p_{wf}) = m(p_i) - \frac{1637\ q_1 T}{kh}\left[\log\left(\frac{t_1 + \Delta t}{\Delta t}\right) + \frac{q_2}{q_1}\ \log \Delta t\right] - \frac{1637\ q_2 T}{kh}\left[\log\left(\frac{k}{\phi \mu c_t r_w^2}\right) - 3.25 + 0.87s\right] \qquad (7)$$

Plotting $m(p_{wf})$ versus $\log\left(\frac{t_1 + \Delta t}{\Delta t}\right) + \frac{q_2}{q_1} \log \Delta t$ on cartesian paper yields a straight line with slope m. Therefore:

$$kh = -\frac{1637\ q_1 T}{m} \qquad (8)$$

Until the data deviates from the straight line portion of the graph, no boundary has been encountered.

The new rate chosen for Emma Lou Gas Unit No. 1, Well No. 1, was 2.0 mmcfpd. The well was tested at this rate for 23 days. The tubing pressure, choke size and rate were monitored continually.

The multi-rate portion of the drawdown test was concluded due to the deadline imposed by the drilling agreement. The total test had lasted 550 hours. Applying the superposition technique and the m(p) method, no boundary was evident (Fig. No. 9).

During the multi-rate test a mechanical problem developed which forced the well to be shut in for a short duration. The flow rate was resumed at 2.0 mmscfpd. At this time the well began to produce additional volumes of water, indicating possible loading of the wellbore. The shut in and subsequent water loading is evident as a change in slope on Fig. No. 9.

The deliverability was predicted using the pseudosteady state flow equation as applied to m(p). The equation is as follows:

$$q = \frac{19.88 \times 10^{-6}\, hk\, T_{sc} \left[m(\bar{p}) - m(p_{wf})\right]}{T p_{sc} \left[\ln \frac{r_e}{r_w} - 0.75 + s' + Dq\right]} \qquad (10)$$

Even though no boundary was encountered, the calculated deliverability was found to be insufficient for an economical prospect.

CONCLUSION

Transient pressure testing is often the most accurate and timely method available to predict both the deliverability and reserves of a deep gas well. Of the transient techniques, drawdown and multi-rate testing are especially attractive because of continued gas sales throughout the test. In high pressure and temperature wells the real gas pseudo-pressure or m(p) method is the only viable technique. Since gas from deep wells tends to be dry, data can be successfully gathered at the surface. A distinct advantage of this technique is not entering the wellbore with any additional equipment. In the subject well test, no boundary was seen during the limited time interval; however, the calculated kh value and resulting deliverability were insufficient to justify continued exploration.

Even though this pressure test was performed without laboratory analysis on fluid and formation properties and in a limited time period, a successful interpretation was made by operations engineers. This reservoir description has been supported by production to date.

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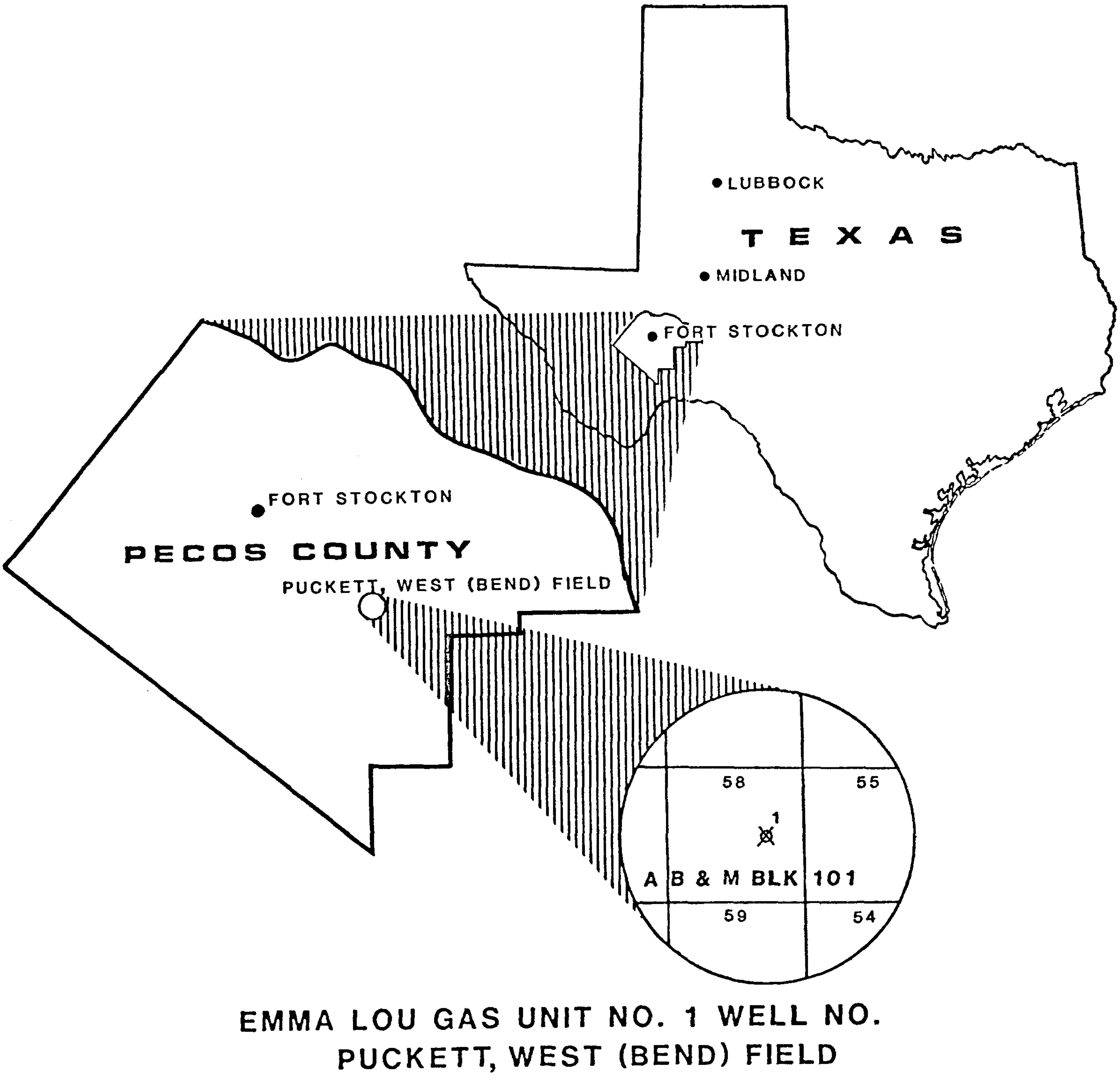
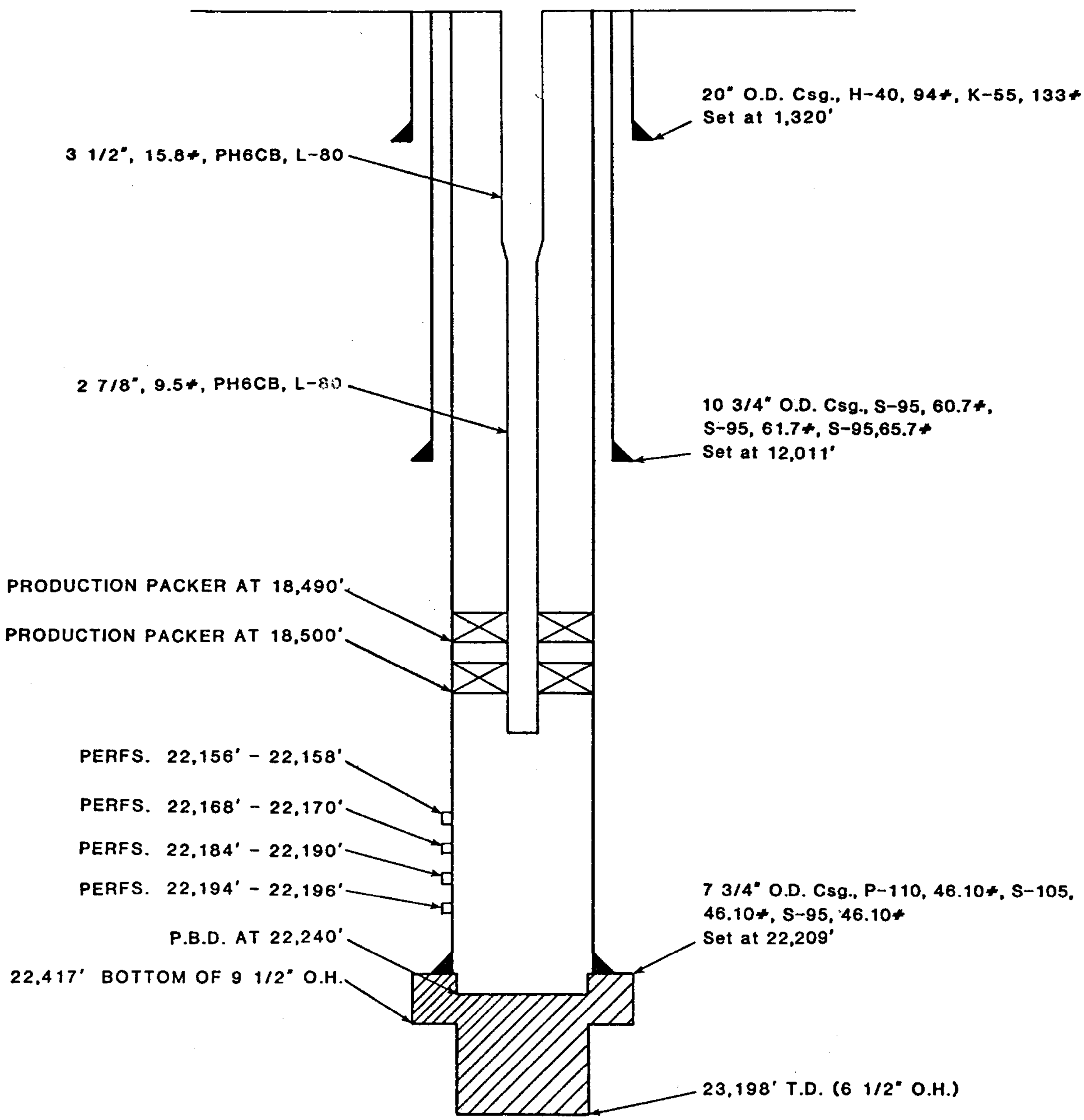


FIGURE 1 - LOCATION MAP

FIGURE 2

EMMA LOU GAS UNIT NO. 1 WELL NO. 1
PUCKETT, WEST (BEND) FIELD
PECOS COUNTY, TEXAS



EMMA LOU GAS UNIT No. 1 WELL No. 1

GAS ANALYSIS

		MOLE %	GPM
HYDROGEN SULFIDE		0.00	
NITROGEN		0.38	
CARBON DIOXIDE		4.88	
METHANE		94.64	
ETHANE		0.09	0.024
PROPANE		0.01	0.003
ISO-BUTANE		0.00	0.000
ISO-PENTANE		0.00	0.000
NOR-PENTANE		0.00	0.000
HEXANES		0.00	0.000
HEPTANES +		0.00	0.000
	TOTAL	100.00	0.027

MIXTURE SPECIFIC GRAVITY: .603

FIGURE No. 3

VISCOSITY VERSUS PRESSURE

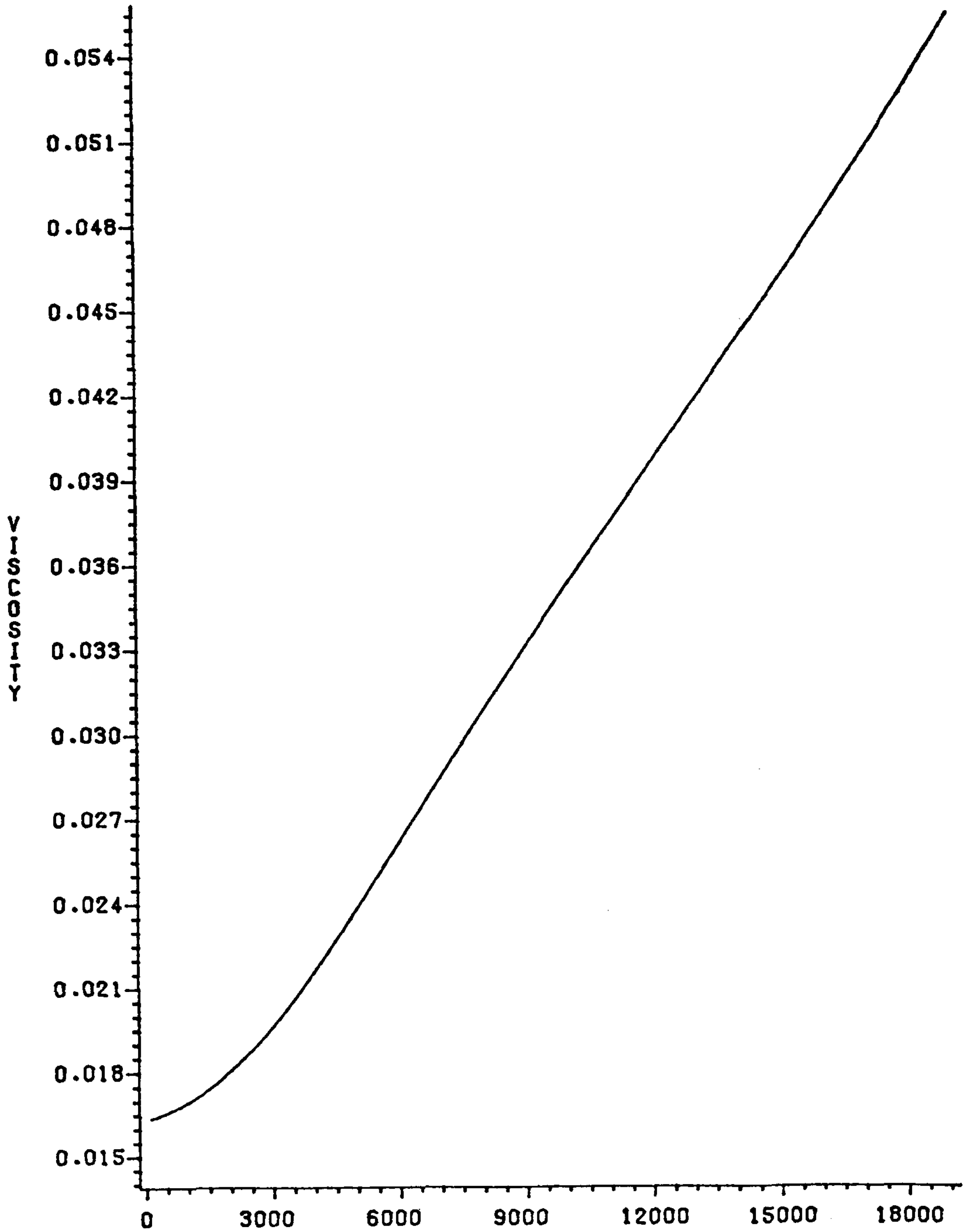


FIGURE 4

GAS DEVIATION FACTOR VERSUS PRESSURE

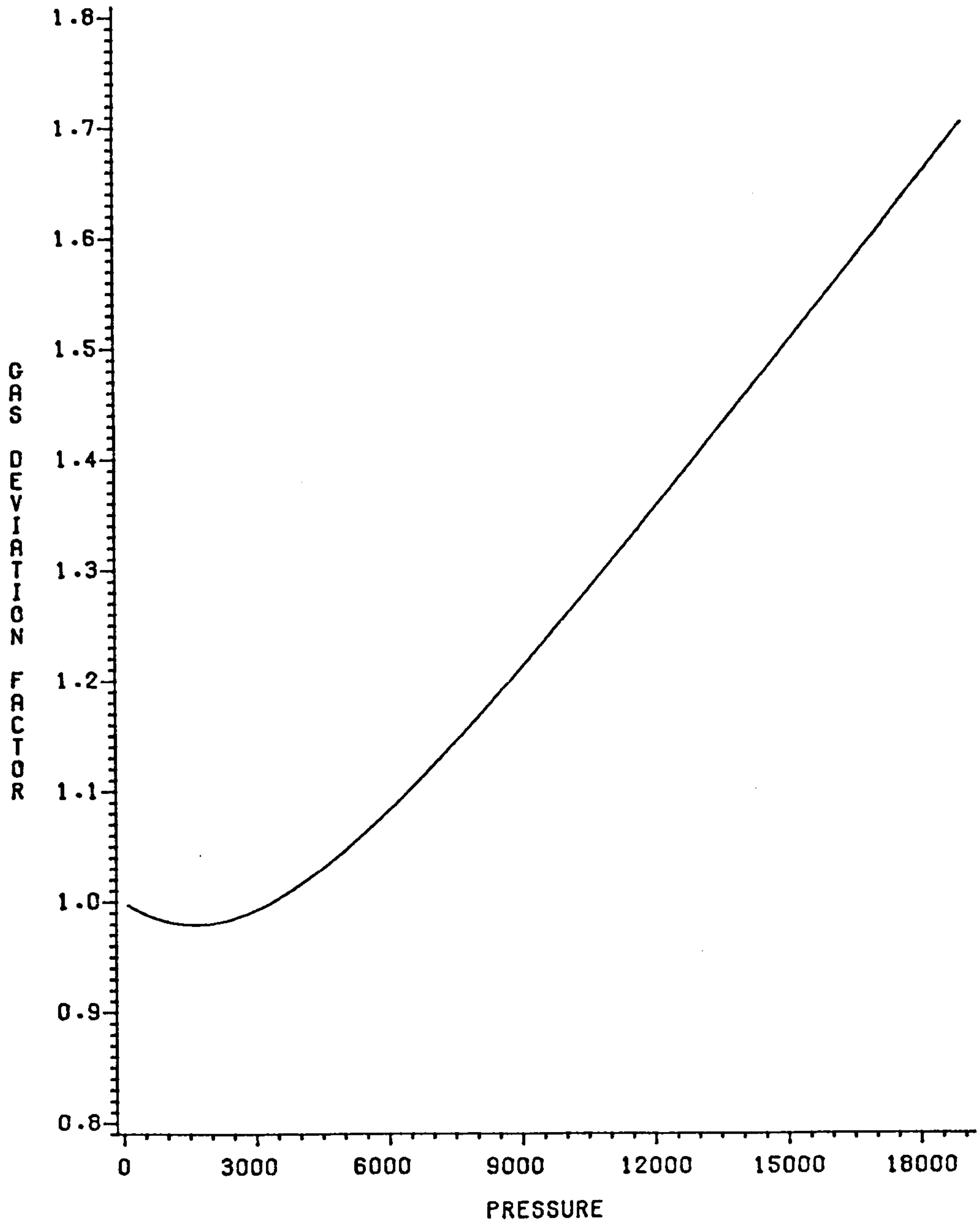


FIGURE 5

P/UZ VERSUS PRESSURE

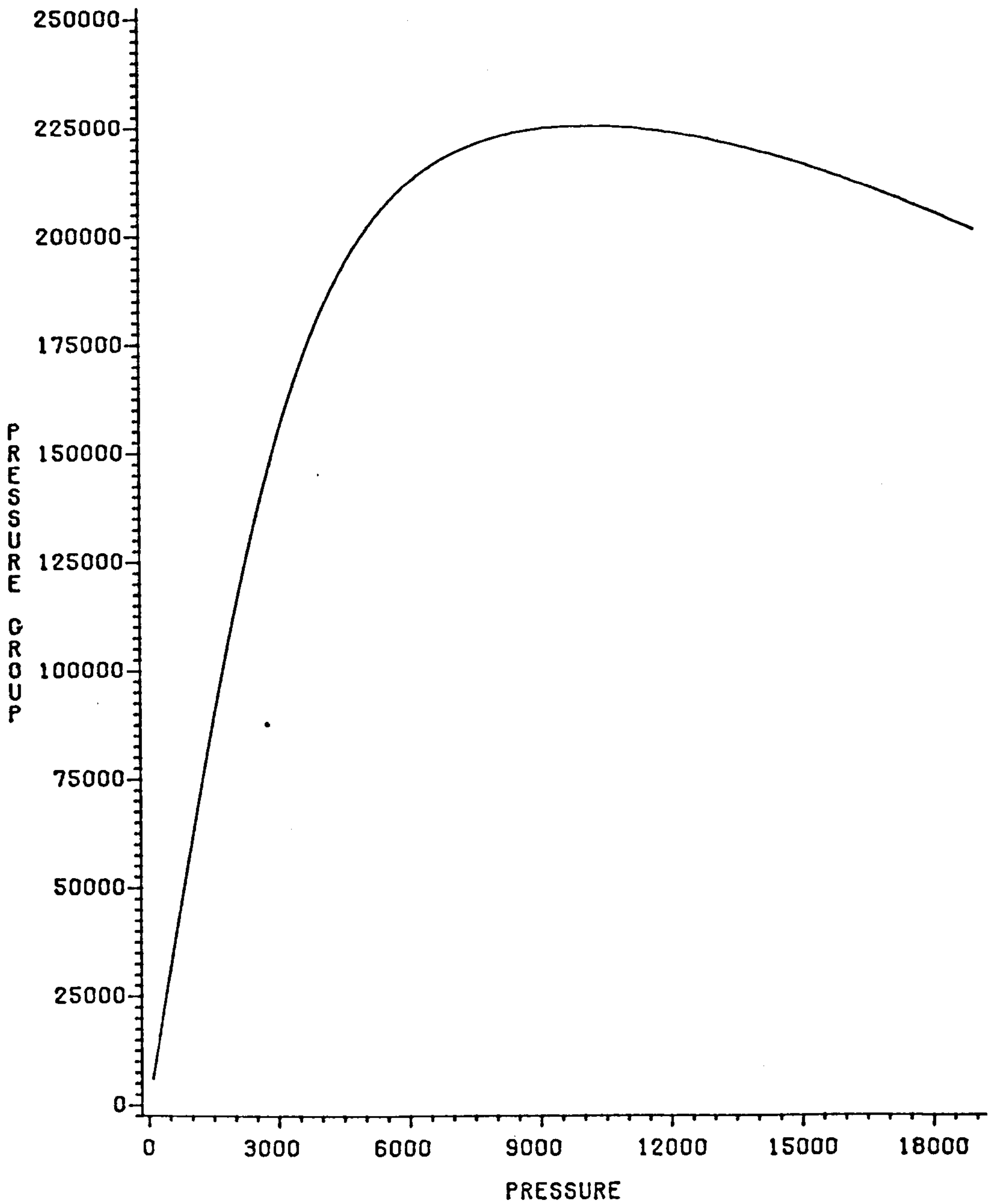
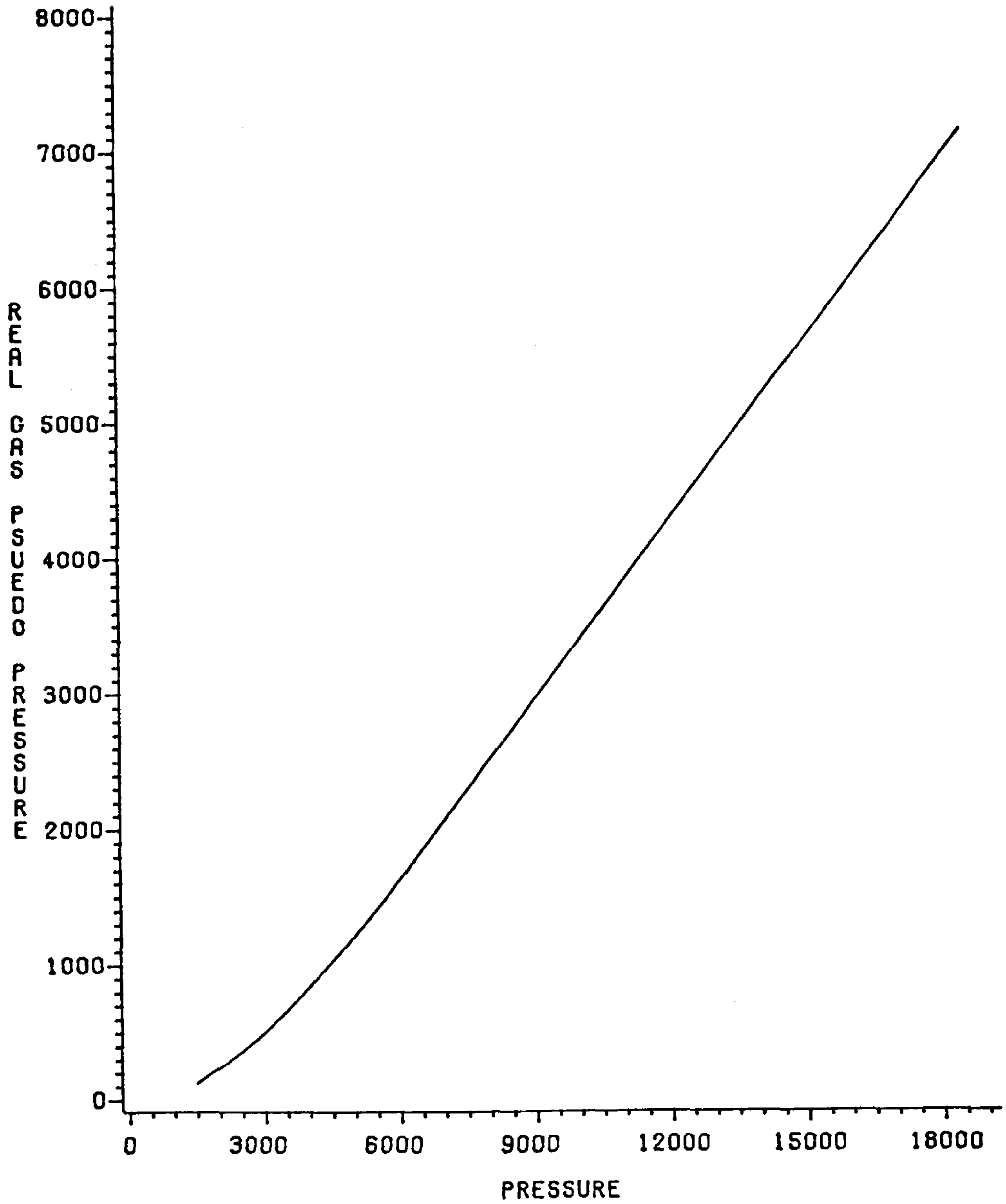


FIGURE 6

REAL GAS PSUEDO PRESSURE VS PRESSURE

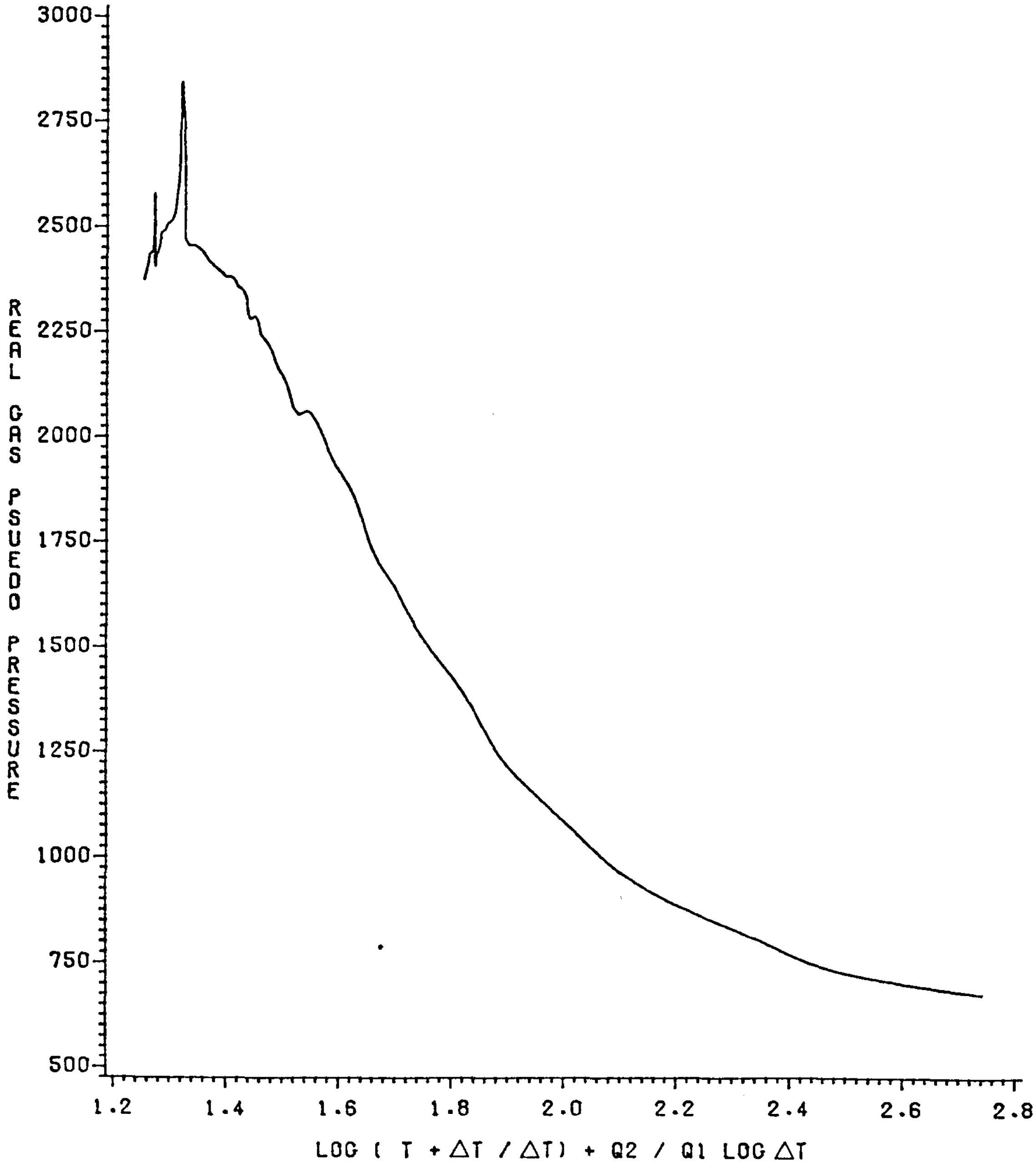


REAL GAS PSUEDO PRESSURE 10 E6
FIGURE 7

DRAWDOWN TEST

FIGURE 8

MULTIPLE RATE TEST



REAL GAS PSUEDO PRESSURE 10 E6

FIGURE 9