THE REAL GAS PSEUDO
PRESSURE FOR GEOTHERMAL STEAM -- SUMMARY REPORT

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INTRODUCTION

The producing characteristics of vapor-dominated geothermal steam reservoirs bear some strong resemblances to those observed in hydrocarbon natural gas reservoirs. Consequently, many geothermal steam well tests are commonly analyzed using flow theory developed for the isothermal flow of hydrocarbon natural gases. Such analysis is most often made using the idealization of perfect gas fluid flow behavior in the reservoir.

This study investigated the real gas flow characteristics of geothermal steam over the ranges of pressure, temperature, and noncondensable gas content commonly found in vapor dominated geothermal systems. Details of this study are available elsewhere (Mannon, 1977).

THEORY

The transient flow of a real gas in an incompressible porous medium is described by a highly nonlinear partial differential equation. For the case of an ideal gas, this equation, while still nonlinear is similar in form to the classical diffusivity equation which describes transient liquid flow in porous media. Aronofsky and Jenkins (1953) provided numerical solutions to this equation which demonstrated that transient ideal gas flow could be analyzed using <u>some</u> of the techniques developed for transient liquid flow.

Al-Hussainy et al. (1966) proposed an integral transformation which converts the form of the nonlinear flow equation for a real gas into one, which, while still nonlinear, is also similar in form to the diffusivity equation. Thus, there exists the possibility that real gas transient fluid flow can be analyzed in terms of the transformed pressure variable using techniques developed for transient liquid flow. This possibility was verified for hydrocarbon natural gases in radial flow systems by Al-Hussainy and Ramey (1966) and Wattenbarger and Ramey (1968).

RESULTS

The integral transformation proposed by Al-Hussainy et al. has been called the "real gas pseudo pressure" and is:

$$m(p) = \int_{p_o}^{p} \frac{p\,dp}{\mu(p)\ z(p)} \quad ;$$

where; m = real gas pseudo pressure
p = pressure
p_o = arbitrary base pressure
μ = viscosity of the gas
z = compressibility factor for the gas

In this study, the real gas pseudo-pressure, m(p), was evaluated for geothermal steams over the range 20 to 1000 psia (2-75 bars), temperature range 300 to 600°F (150-325°C) and various noncondensable gas contents. Other physical properties relevant to single-phase isothermal gas flow in porous media were also evaluated and compiled.

The m(p) function was found to be linear in p^2 for low pressures (up to approximately 150 psia or 10 bars). This is depicted in Fig. 1. This behavior is described by a relationship of the form:

$$m(p) = a_1 p^2 + b_1 \qquad (1)$$

At higher pressures a graph of log m(p) vs. log p produced straight lines of the form:

$$m(p) = a_2 p^{b_2} \qquad (2)$$

where b_2 varied between 2.045 and 2.099 (Fig. 2). High accuracy curve fits of Figs. 1 and 2 are presented in Tables 1 (Engineering Units) and 2 (International Units). Varying the mole fraction of carbon dioxide in the gas up to a mole fraction of 60% did not change the basic shape of the curves in Figs. 1 and 2, and tended to increase the value of m(p) by a factor of less than 2.

DISCUSSION

These results will allow the reservoir engineer to more accurately analyze transient flow of superheated geothermal steams. Geothermal steam wells have traditionally been analyzed using the ideal gas flow model, described by Eq. 1, without quantitative justification. The results of this study will allow for quantitative justification of the ideal gas flow assumption, where possible. Alternatively, they will facilitate use of the more correct pseudo-pressure function when analyzing geothermal steam wells.

REFERENCES

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TABLE 1

ANALYTICAL EQUATIONS FOR APPROXIMATING

THE REAL GAS PSEUDO-PRESSURE

(Engineering Units)

Temperature	Limits	Curve Fit Equation
300°F	$p \leq 60$ psia	$m(p) = 36.88p^2 - 8396$
350°F	$p \leq 70$ psia*	$m(p) = 33.93p^2 - 7819$
	$p \geq 70$ psia	$m(p) = 21.60p^{2.095}$
400°F	$p \leq 80$ psia	$m(p) = 31.41p^2 - 7248$
	$p \geq 80$ psia	$m(p) = 21.33p^{2.080}$
450°F	$p \leq 100$ psia	$m(p) = 29.25p^2 - 6769$
	$p \geq 100$ psia	$m(p) = 19.94p^{2.078}$
500°F	$p \leq 140$ psia	$m(p) = 27.36p^2 - 6336$
	$p \geq 140$ psia	$m(p) = 18.65p^{2.075}$
550°F	$p \leq 160$ psia	$m(p) = 25.71p^2 - 5946$
	$p \geq 160$ psia	$m(p) = 18.02p^{2.068}$
600°F	$p \leq 190$ psia	$m(p) = 24.31p^2 - 5916$
	$p \geq 190$ psia	$m(p) = 18.25p^{2.053}$

* At the meeting point, the upper and lower equations agree to 3 or more significant figures.

TABLE 2

ANALYTICAL EQUATIONS FOR APPROXIMATING

THE REAL GAS PSEUDO-PRESSURE

(International Units)

Temperature	Limits	Curve Fit Equation
150°C	$p \leq 4$ bars	$m(p) = 36.80p^2 - 40.65$
175°C	$p \leq 5$ bars *	$m(p) = 34.20p^2 - 38.60$
	$p \geq 5$ bars	$m(p) = 27.89p^{2.099}$
200°C	$p \leq 6$ bars	$m(p) = 31.93p^2 - 36.74$
	$p \geq 6$ bars	$m(p) = 26.78p^{2.081}$
225°C	$p \leq 7$ bars	$m(p) = 29.93p^2 - 34.94$
	$p \geq 7$ bars	$m(p) = 24.96p^{2.079}$
250°C	$p \leq 10$ bars	$m(p) = 28.31p^2 - 37.04$
	$p \geq 10$ bars	$m(p) = 23.35p^{2.076}$
275°C	$p \leq 10$ bars	$m(p) = 26.62p^2 - 33.09$
	$p \geq 10$ bars	$m(p) = 22.25p^{2.069}$
300°C	$p \leq 12$ bars	$m(p) = 25.23p^2 - 32.74$
	$p \geq 12$ bars	$m(p) = 21.66p^{2.056}$
325°C	$p \leq 13$ bars	$m(p) = 23.93p^2 - 30.66$
	$p \geq 13$ bars	$m(p) = 21.11p^{2.045}$

* At the meeting point, the upper and lower equations agree to 3 or more significant figures.

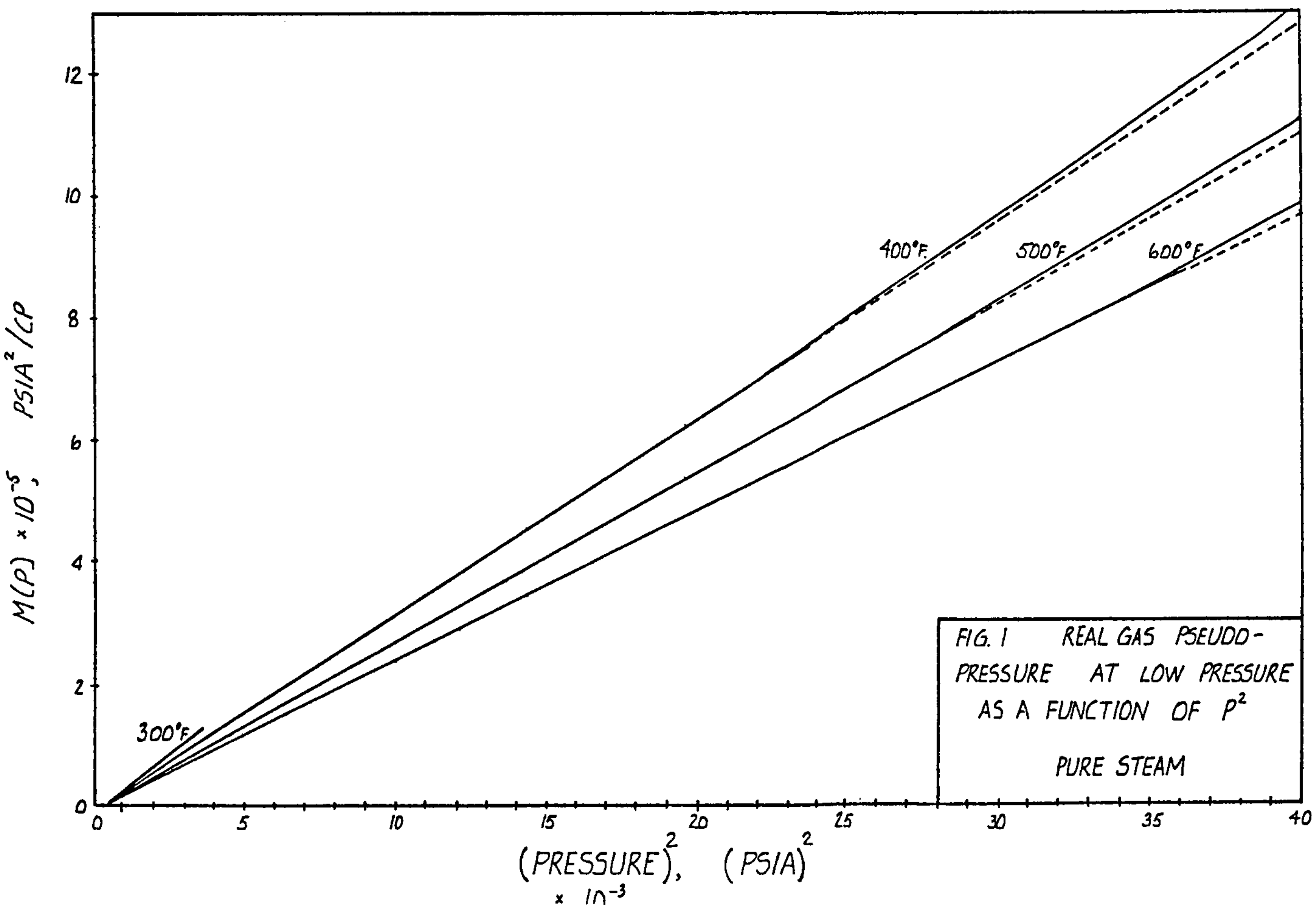

FIG. 1 REAL GAS PSEUDO-PRESSURE AT LOW PRESSURE AS A FUNCTION OF P^2

PURE STEAM

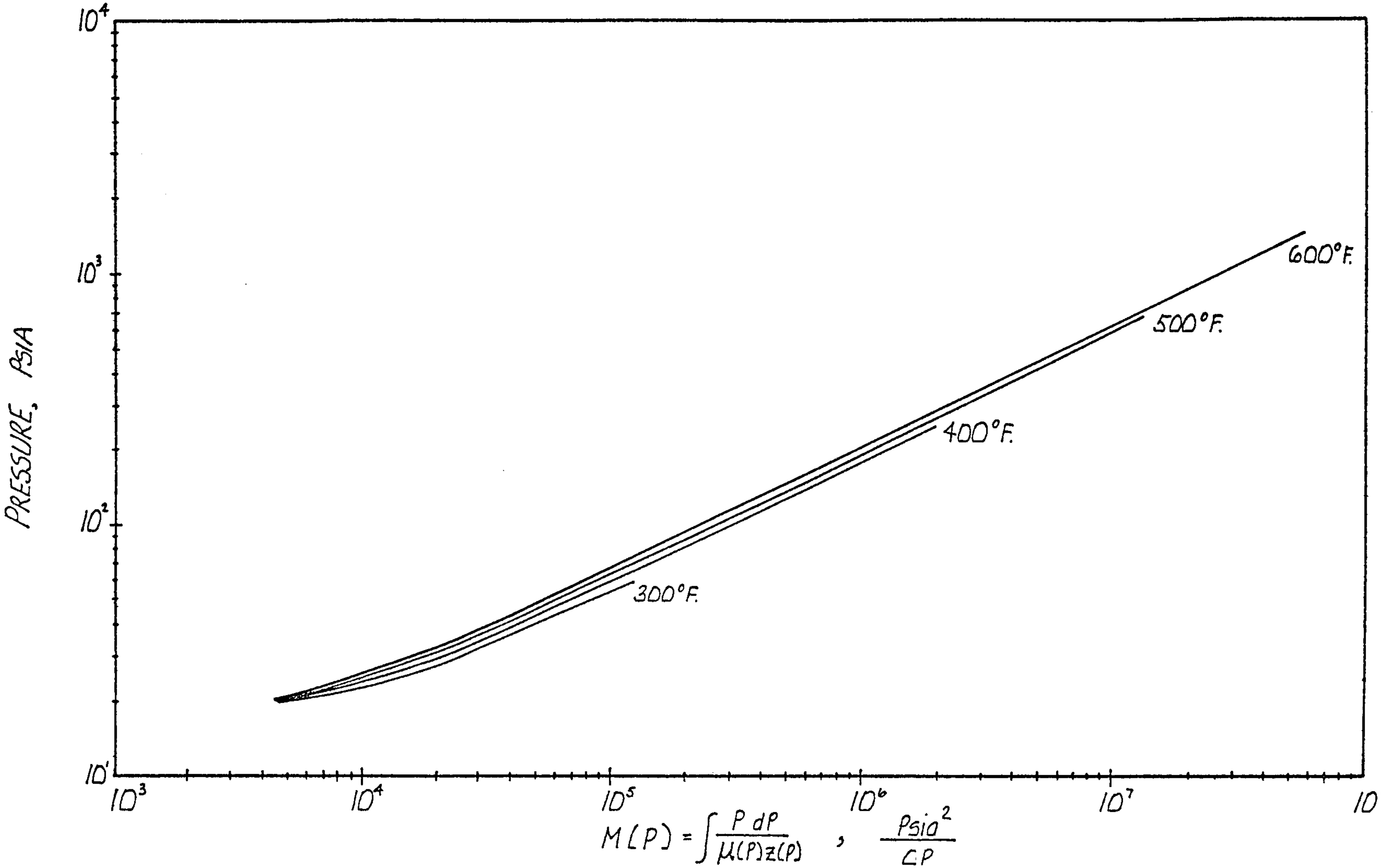

FIG. 2 REAL GAS PSEUDO-PRESSURE M(P) FOR PURE STEAM