ISOENTHALPIC FLASHING POINT COMPRESSIBILITY OF GEOTHERMAL FLUIDS WITH LOW CO_2 CONTENT

Z. UGUR[1] AND A. SATMAN[1]

[1] Petroleum and Natural Gas Engineering Dept., ITU, Istanbul, Turkey

SUMMARY-Noncondensable gases in geothermal fluids have major effects on the behavior of the reservoir and fluid flow. The most common and dominant noncondensable gas in geothermal fields is carbon dioxide. Therefore effects of the CO_2 content on the flow characteristics and thermodynamic properties must be known. In this study the compressibility of the geotheml fluids containing low dissolved CO_2 at flashing point is formulated for isoenthalpic phase change. The compressibility called as isoenthalpic flashing point compressibility can be calculated with well-known parameters such as saturated water and steam densities, steam pressure and Henry's constant for CO_2. New easy to use graphs to estimate the compressibility for such systems are presented. Correction for ionic strength of the brine is also considered. The practical use of the compressibility is illustrated by using a material balance method to estimate the fluid content of a geothermal reservoir.

1. INTRODUCTION

The water produced by geothermal wells most frequently contains noncondensable gases and dissolved solids. They have considerable effects on the behavior of the reservoir and fluid flow. In its natural state, the partial pressure of the noncondensable gas causes the reservoir to flash at a higher pressure than does pure water. The presence of noncondensable gases in produced fluid dominates the transport and thermodynamical properties of the flow. The most common and dominant gas in geothermal fields is carbon dioxide. The studies (Sutton (1976), Parlaktuna (1988), Alkan and Satman (1990), Ugur (1997)) show that small differences in the CO_2 content of the reservoir fluid causes significant changes in the pressure, enthalpy and gas content of production fluid.

In general the geothermal fluids are brine-CO_2 solutions with relatively low dissolved solid and noncondensable gas content. Thermodynamic properties and the pressure-volume- temperature (pVT) behavior of these type solutions have been studied experimentally and theoretically (Ellis and Golding (1963), Edwards et al (1978), Jin and Donhoue (1988), Enick and Klara (1990), Satman and Alkan(1990), Crovetto (1991), Joyce and Holloway (1993), Oddo and Tomson (1994), Millero (1995), Ugur et al (1996)). Some of these studies presented the models which vary according to the parameters such as temperature, pressure and ionic strength of the solutions. Mostly they can be employed to represent the two-phase domain characteristics of the geothermal fluids.

In this paper, the compressibility of brine-CO_2 solutions at the flashing point, that is one of the most important thermodynamic properties, is formulated with the known parameters for the isoenthalpic phase change and called as isoenthalpic flashing point compressibility.

Ionic strength effect on the compressibility is calculated and presented. It is also demonstrated by a case study that isoenthalpic flashing point compressibility can be used for estimating initial fluid volume of a geothermal reservoir.

2. ISOENTHALPIC FLASHING POINT COMPRESSIBILITY

Compressibility of the brine-CO_2 solutions especially at the flashing points depends on gas CO_2 compressibility, because the vapor phase of geothermal fluid is composed of only gas CO_2 under these conditions. Figure 1 shows the pressure-enthalpy- temperature diagram for a given brine-CO_2 solution *(Ugur,*1997).

It reveals extremely different phase behavior at low steam quality values as compared to the enthalpy diagram for pure water system. As seen in Fig. 1 one *can* say that brine-C02 solutions show isoenthalpic behavior during the phase change at relatively low steam quality values (up *to* 3 **wt** %). Using **this** characteristic, the compressibility for a brine-CO_2 system at flashing point conditions **can** be formulated at fixed temperature (T) as follows :

$$c_c = \frac{K_H \rho_w}{\rho_s} \frac{18 p_s}{44 p_{CO_2}} \qquad (1)$$

Where:

c_c : Isoenthalpic flashing point compressibility, 1/Pa
K_H : **Henry's** constant, 1/Pa
Ps : Steam pressure at T, Pa
p_{CO_2} : Partial pressure of CO_2 at T, Pa
ρ_W : Water density, kg/m^3
ρ_s : Steam density, kg/m^3

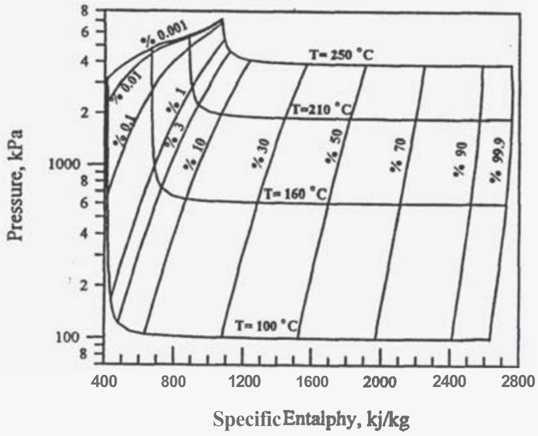

Figure 1 Pressure-enthalpy-temperature diagram for brine - CO_2 solution with **0.05** M ionic strength and 1.5 **wt** % initial dissolved CO_2. (Percentage values in two - phase region represent steam quality) *(Ugur,* 1997).

The derivation of Equation 1 is given in Appendix A. Values of densities and Henry's constant were calculated using the pVT model presented by **Ugur** (1997). For **Henry's** constant pVT model employs Satman's (1990) correlation which **was** developed using **mainly** Ellis-Golding (1963) experimental values. **This** correlation is valid up to **300** °C temperatures and 2 **M** values of ionic strength (M). Furthermore densities of pure water **and** steam and **steam** pressure can be taken **from** steam tables.

Figure **2** gives the isoenthalpic **flashing** point compressibility values **as** a function of the CO_2 concentration **and** temperature for pure water-CO_2 solutions. Range of temperature **and** CO_2 concentration of the solutions were chosen considering geothermal reservoir conditions in Turkey. **As** seen in Fig. 2 the lower **the** dissolved CO_2 concentration in solution is, the greater the compressibility of the solution becomes.

In Fig. 3 ionic strength effect of the solutions **on** compressibility is given **as** a function of temperature. Fig. 3 gives the **ratio** of the Compressibility of brine-CO_2 solutions (c_c) to the compressibility of water-CO_2 solutions (c_c (M=0)). The values for c_c (M=0) are taken from Fig. 2. Note that presence of the dissolved **solids** in brine lowers compressibility. Using Fig. 1 and **2**, one **can** estimate isoenthalpic **flashing** point compressibility for brine-CO_2 solutions. For example, the compressibility of the brine- CO_2 solution with **0.5** M ionic strength and **1.2 wt** % CO_2 content at 200 °C can be found **as** follows. First, **from** Fig. 2 the compressibility value for water-1.2 **wt** % CO_2 solution corresponding to the given temperature is read to be **8.0 x** 10^{-5} 1/kPa. **Then, from** Fig 3, the ratio (c_c/c_c (M=0)) corresponding to the given ionic **strength** and temperature is read to be **0.54.** Finally the last **value** is multiplied by **the** compressibility value read **from** Fig. 1. The result, 4.32 x 10^{-5} 1/kPa, is the isoenthalpic flashing point compressibility of the given brine- CO_2 solution.

3. PRACTICAL USE OF ISOENTHALPIC FLASHING POINT COMPRESSIBILITY

Isoenthalpic flashing point compressibility can also be used to estimate the initial fluid volume of a geothermal reservoir where isoenthalpic phase behavior exists, as illustrated below:

Consider a geothermal reservoir in which there is a production and water recharge, a **simple** volumetric balance **similar** to the one for volumetric oil reservoirs (Craft and Hawkins, 1959) can be written **as** follows:

$$\frac{B_w W_p - W_e}{(c_f + c_c)\Delta p} = V_{pi} \qquad (2)$$

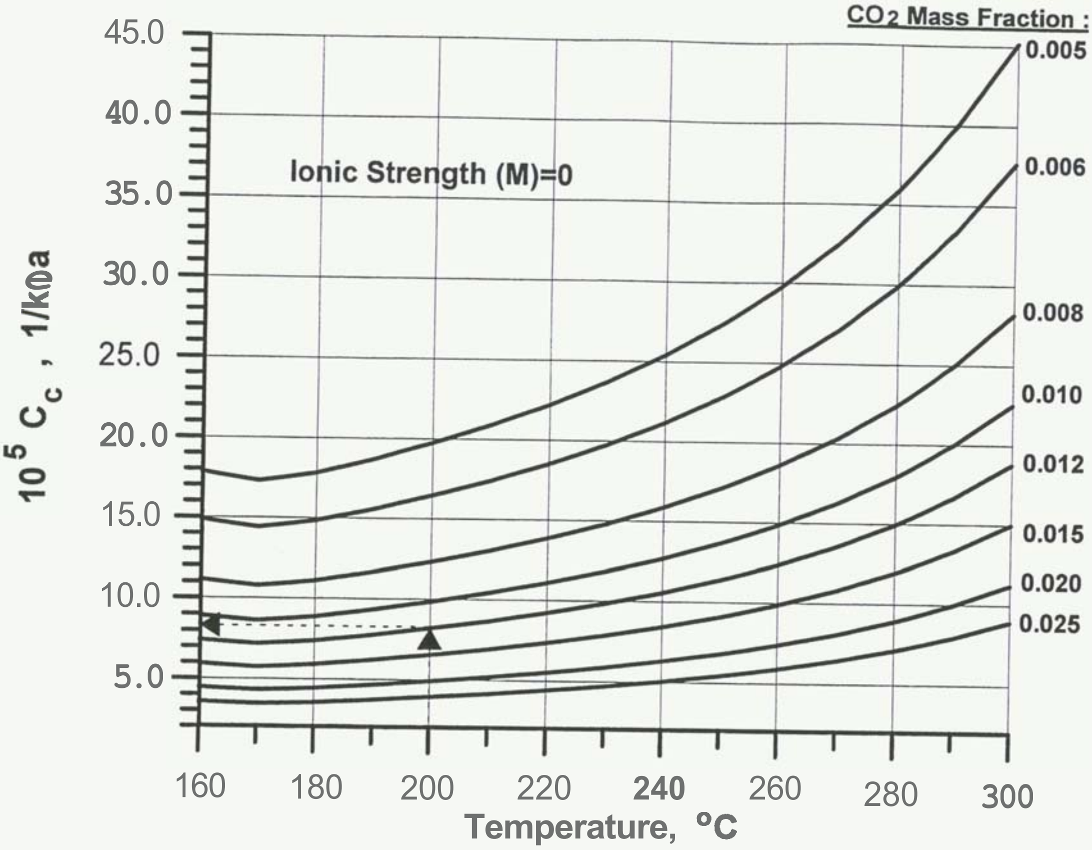

Figure 2 Isoentalpic flashing point compressibility for various water-C02 solutions

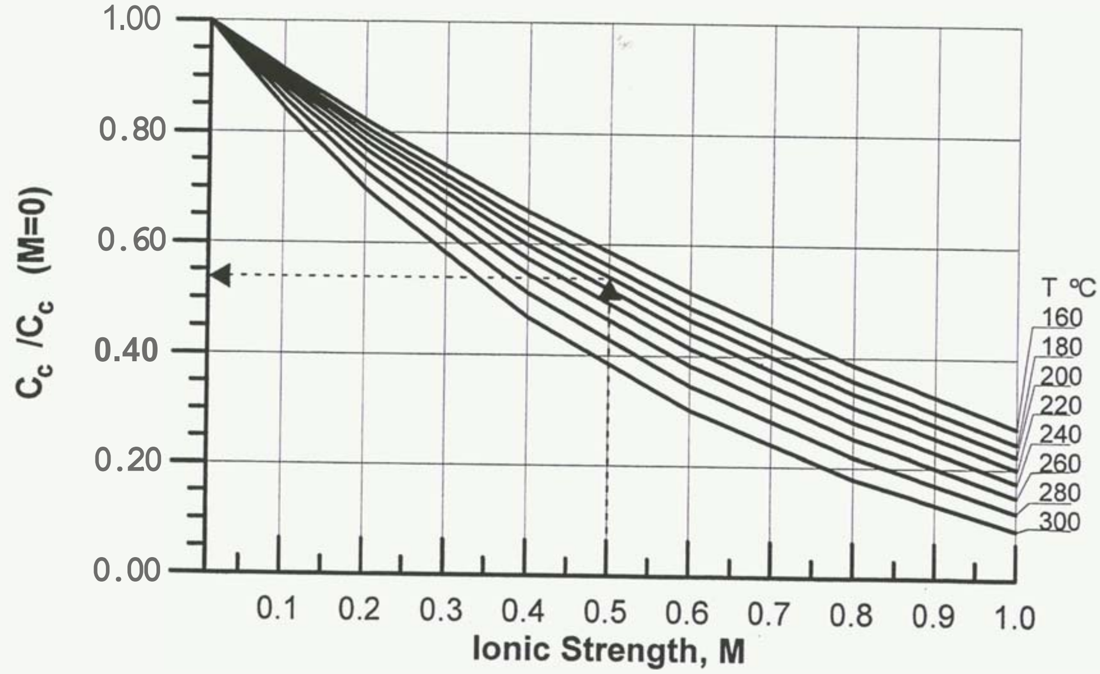

Figure 3 Ionic strength effect on the compressibility of brine-CO_2 solutions

Where

V_{pi} : Initial fluid volume,
B_wW_p: Produced volume,
W_e : Volume of water influx into the reservoir,
c_f : Formation compressibility,
Ap : Pressure drop as a result of production.

Neglecting the formation compressibility, since its magnitude is much smaller than the isoenthalpic flashing point compressibility, then gives the following equation:

$$V_{pi} = \frac{1}{c_c}\frac{\Delta V}{\Delta p} \qquad (3)$$

Where: $\Delta V = B_wW_p - W_e$

Equation **3** indicates that the initial pore volume of a geothermal reservoir **can** be estimated if pressure drop, Ap, is **known** as a function of volume change in the system, ΔV.

Applicability of **Equation** 3 is demonstrated by using the observed production behavior of the Kizildere geothermal field. The modelling study of the field (**Alkan** and Satman, **1990)** and measured reservoir pressure- cumulative production **data** clearly show the isoenthalpic two-phase behavior. During the time period between **1991** and **1995,** the average production rate from the field was **7** million ton per year and natural water **influx** into the reservoir was estimated to be **550** ton/hour (MTA, Satman et al. **1996).** Well **KD-7** was chosen to be the representative average well for the field because of its central location in the reservoir and its reliable pressure data measured during the two-phase production period. Data obtained from this well are **200** °C bottom hole temperature and 8.1 kPa pressure drop per 10^6 ton fluid production, and geothermal fluid with **1.2 wt %** initial dissolved CO_2 and ionic strength of **0.07** M (Satman et al.**(1996),** Tan **(1984)).**

Using the representative **data** in Figs. **2** and **3,** flashing point compressibility, c„ is determined to be **7.6×10^{-5} 1/kPa.** Fluid volume change in reservoir, ΔV, is calculated using the natural water **influx** and production values. Substituting the respective values into Equation **3,** the initial fluid volume of the Kizildere geothermal field is obtained to be **603** million cubic meters. **This** checks perfectly well with the initial estimate of the reservoir fluid volume of **600** x 10^6 cu m (**UN** Repeort **, 1974).**

4. REFERENCES

Alkan, H., Satman, A. **(1990)** A New Lumped Parameter Model For Geothermal Reservoirs in the Presence of Carbon Dioxide, ***Geothermics*** **19, No.5, 469-479.**

Craft, B.C. Hawkins, M.F. Jr. **(1959).** ***Applied Petroleum Reservoir Engineering,*** Prentice-Hall Inc., New Jersey

Crovetto, R. **(1991)** Evaluation of Solubility Data of the System CO_2-H_2O **from 273** K to the Critical Point of Water, ***J. Phys. Chem. Ref: Data,*** **20, No.3,575-589.**

Edwards, T. J., Maurer, G., Newman, J., Prausnitz, J. M. **(1978).** Vapor Liquid Equilibria in Multicomponent Aqueous Solutions of Volatile Weak Electrolytes, ***AIChE Journal,*** **24, No.6, 966 -975.**

Enick, R.M., Klara, S.M. **(1990).** CO_2 Solubility in Water and Brine Under Reservoir Conditions, ***Chem. Eng. Comm.*** **90, 23-33**

Ellis, E. J., Golding, R. M. **(1963).** The Solubility **of** C02 Above **100** °C in Water and in **Sodium** Chloride Solutions, ***Am. J. Sci.*** **261, 47- 60.**

Jin, G. Donhoue, M. D. **(1988).** ***An*** Equation of State for Electrolyte Solutions. **2.** Single Volatile Weak Electrolytes in Water, ***Ind. Eng. Chem. Res.*** **27, 1737- 1747.**

Joyce, D. B., Holloway, J. R. **(1993).** ***An*** experimental determination of the thermodynamic properties of H_2O-CO_2-NaCl fluids at **high** pressure and temperatures, ***Geochmica et Cosrnochimica, Acta*** **57,** p. **733-746.**

Millero, F, J. **(1995).** Thermodynamics of Carbon Dioxide System in the Oceans, ***Geochimica et Cosmochimica, Acta.*** **59, No. 4, 661-667.**

MTA Mineral Research and Exploration Institute **(1992).,** ***Cleaning and Test Report for Kizildere Geothermal Field.*** prepared by Drilling Office of MTA, **Ankara.**

Oddo, J.E., **Tomson,** M.B. **(1994).** Why Scale **Forms** and How to Predict It, ***SPE Production and Facilities,*** February, **.47-54.**

Parlaktuna, M. **(1988).** ***Effect of Carbon Dioxide on PVT Behavior of Geothermal Fluids and Prevention of Calcite Deposition by Inhibitor Injection,*** Ph. D. Thesis **METU** Petroleum and Natural **Gas** Engineering Depart., Ankara.

Satman, A., *Alkan,* H. **(1990).** Modelling of CO_2-Brine Solutions in Wellbore and Calcite Scaling, 8th Petroleum Congress and Exhibition of Turkey, **16-20** April, Ankara.

Satman, A., Serpen, U., **Ugur,** Z., Türkmen, N. **(1996).** Importance of Reinjection at the Kizildere Geothermal Field, ***Proceedings,*** 11th Petroleum Congress and Exhibition of Turkey **15-17** April **,** Ankara, **98-74.**

Sutton, F. M. **(1976).** Pressure-Temperature Curves for a Two-Phase Mixture of Water and Carbon Dioxide, ***New Zealand Journal of Science,* 19, 297-301.**

Tan, E. **(1984).** Reservoir Characteristics **of** the Kýzýldere Geotherxnal Energy Field, Seminar on Utilization of Geothermal Energy for Electric Power Production and Space Heating **(14-17** May) Florence, Italy.

Ugur, Z. (1997). ***Modelling of Calcium Carbonate Precipitation in Oil and Geothermal Fields,*** Ph.D Thesis, **ITU,** Petroleum and Natural **Gas** Engineering Department, Istanbul.

Ugur, Z., Alkan, H., Serpen, U., **Satman, A. (1996).** The pVT Behavior of Brine-CO_2 Solutions, 11th Petroleum Congress and Exhibition of Turkey **(11-15** April), **,** Ankara, ***Proceedings,*** 207-2**15.**

United Nations, (1**974). *Geothermal Energy Survey of Western Anatolia, Project Findings and Recommendations,*** New York

Appendix A -Derivation of Isoenthalpic Flashing Point Compressibility

The compressibility is defined as the change in volume per unit volume per unit change in pressure, or

$$c = -\frac{1}{V}\frac{dV}{dp} \qquad \text{(A-1)}$$

The compressibility resulting **from** the carbon dioxide can be written similarly to Equation **A-1** as:

$$\frac{\Delta V}{V} = c_c \, \Delta p_{CO_2} \qquad \text{(A-2)}$$

The volume changes when CO_2 leaves the water solution. Hence:

$$\frac{\Delta V}{V} = \frac{(\Delta m_{CO_2})_l}{\rho_{CO_2}} \rho_l \qquad \text{(A-3)}$$

The-amount of the CO_2 in the liquid phase is small and neglected in the liquid density, that is:

$$\rho_l = \rho_w \qquad \text{(A-4)}$$

By using Equations A-2, A-3 and A-4 we can write for the compressibility:

$$c_c = \frac{(\Delta m_{CO_2})_l}{\rho_{CO_2}} \rho_w \frac{1}{\Delta p_{CO_2}} \qquad \text{(A-5)}$$

Henry's law is employed to give

$$(\Delta m_{CO_2})_l = K_H \Delta p_{CO_2} \qquad \text{(A-6)}$$

Substituting Eq. **A-6** into Eq. **A-5** results in the final equation for the isoenthalpic flashing point compressibility for brine-CO_2 solutions:

$$c_c = \frac{K_H}{\rho_{CO_2}} \rho_w \qquad \text{(A-7)}$$

Assuming

$$\frac{\rho_s}{\rho_{CO_2}} = \frac{18}{44}\frac{P_s}{P_{CO_2}} \qquad \text{(A-8)}$$

then isoenthalpic flashing point compressibility is obtained as follows:

$$c_c = \frac{K_H}{\rho_s} \rho_w \frac{18}{44} \frac{p_s}{p_{CO_2}} \qquad \text{(A-9)}$$