THE WELLBORE SIMULATOR SIMU93

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1. ABSTRACT

In this paper the wellbore simulator SIMU93 is described. The code can be directly applied to a variety of Production and Reservoir Engineering problems, usually, within thermodynamic conditions found in two-phase geothermal wells built in Mexico.

SIMU93 has several featured parts, among them are the following: simulation of adiabatic flow in a two-phase three component ($NaCl-H_2O-CO_2$) system in both directions, that is, from wellhead to bottom hole, and vice versa; thermodynamic tables in SIMU93 can handle up to 6 Mol NaCl/kg H_2O concentrations and fluid temperatures up to 325 "C.

A correlation to estimate two-phase three component mass flow rates discharging to the atmosphere at the speed of sound is also presented. This correlation is derived from the James' Method.

2. INTRODUCTION

In the last fifteen years several wellbore simulators have been developed for the Geothermal Industry (Ortiz (1983), Hadgu et al. (1989), S. Upton (1990), and Battistelli (1992)) as a support of Production and Reservoir Engineering studies, however some of them still disregard the presence of gases and dissolved salts (Ortiz (1983), and S. Upton(1989)). The effect of gases and dissolved salts alter the thermodynamics of pure water system, according to the concentration of each component, so that, wellbore simulators that do not consider gases and dissolved salt contents are only applicable to cases with very small concentrations.

On the other hand, the development of two-phase multi-component (more than three components) wellbore simulators is still tedious and complex not only because of the absence of complete thermodynamic tables but also because of the nonexistence of a method to evaluate these mass flow rates.

In this paper, the two-phase multicomponents flow is simplified as a two-phase three component ($NaCl-H_2O-CO_2$) flow problem considering that total dissolved solids (TDS) can be replaced by an equivalent NaCl content, and the gases are treated as gaseous CO, only, because it represents about 90% of the total weight of non-condensible gases mixture.

SIMU93 the most recent simulator of the SIMU's family is a mnemonic for simulator, and 93 represents the year the simulator 'was finished. Although the architectural structure of SIMU89 is preserved, SIMU93 differs in that different thermodynamic tables, in their respective codes are used.

SIMU93 uses the reported data of Ellis (1963), Haas (1976 a,b), and Pritchett et al. (1981) as thermodynamic tables . Some of these data are utilized in original form, while others were transformed to the SI units, and still others were modified to refer to the triple point of pure water. In addition, SIMU93 solves the Adiabatic Flow Problem of Two-Phase Three Component System, under One-Dimension-Steady-State regime, by using a Pseudo-homogeneous flow model. This model considers the frictional losses by using the Colebrook-White correlation.

The flow parameters employed in SIMU93 are taken from the DATA.DAT file and are as follows. Total mass flow rate [kg/s]. Specific enthalpy of the mixture [kJ/kg]. Fluid temperature [C]. NaCl concentration [Mol NaCl/kg of H_2O]. Total fluid pressure [MPa] or the gas/gas+steam ratio. Number of different diameters involved in the simulation. Control of the length increment to write on the output file. Direction of the calculus [+1 from wellhead to bottom hole, -1 from bottom hole to the wellhead]. Angle between the axis of the wellbore and the imaginary axis in the direction of the gravitational force [Deg]. Wellbore's pipe design parameters, i.e. pipe lengths [m]; pipe diameters [m]; and pipe roughness [m], are also read from the DATA.DAT file. After the running of SIMU93 the resulting data is written on three files: Presgrap.prt; Tempgrap.prt; and Results.dat, for different purposes, such as the construction of a graphic for pressure profile.

Simultaneously, a two-phase three component flow equation was developed to evaluate the NaCl and CO_2 mass flow rates, and also the pure water two-phase flow. This equation is equal in form to the empirical equation developed by James (1966). but is extended for the case of a $NaCl-H_2O-CO_2$ system. The solution of the equation requires the following information: the brine flow rate [kg/s] measured in the weir box and its NaCl concentration [Mol NaCl/kg de H_2O]; the gaslgas-steam ratio at lip conditions; and the lip fluid pressure [MPa] and local atmospheric pressure [MPa].

In advance, work is being done to link, in the near future, Simu93 with a three dimensional reservoir model, in order to simulate the whole system, as in the works discussed in Murray and Gunn (1993), and Hadgu et al. (1993).

3. PREVIOUS WORKS

Battistelli et al. (1992) present their experiences using the Profili 'simulator on the high-salinity, high temperature, liquid dominated

reservoir of the Asal Field, Republic of Djibouti. Battistelli's simulator includes salts and carbon dioxide effect on global energy balance, based on Barelli's work (Barelli et al. (1982)).

Probst et al. (1992) wrote a review of the works done by Gould (1974), Upadhyay et al. (1977), Ambastha and Gudmundsson (1986), Barelli et al. (1982), Tanaka and Nishi (1988), and Freeston and Hadgu (1988), in which several correlations were compared, among those correlations were the following: Hagedorn and Brown, Aziz, Orkiszewski, Beggs and Brill, and Barelli. Not all of these correlations included the effects of salts and non-condensable gases. They also made a comparison between models comprised into the wellbore simulator Wellsim version 2, marketed by Geothermal Energy New Zealand Limited. Wellsim incorporates not only the version 1 pressure drop model of Hadgu and Freeston, but also the Azis, Duns and Ros, Hagedorn and Brown, and Orkiszewski models. They performed in addition simulations utilising the Ansary and the Beggs and Brill pressure drop models. They concluded that no single model can simulate all of the test wells. However they claimed that the Duns and Ros Correlation performed better than the other correlations in most types of geothermal wellbore conditions, but this conclusion was in general due to the small sampling of available data. For high enthalpy wells they suggest the use of Wellsim.

4. COMPARISON OF SIMU93 AND WELLSIM

Using data from wells in the Los Azufres Geothermal Field the results of Simu93, Wellsim, and Simu89 were compared. Figure 1 ilustrates the flowing pressure measured inside well Az-18, during March 1986 (S. Upton (1986)). Also shown in this figure are the results of Simu89, Simu93, and Wellsim (results of the five correlations included in Wellsim). From this graph it is readily observable that the best fittings to the measured data were obtained with Simu89, Simu93, and the Azis correlation. In Fig. 2 the flowing pressure measured inside well Az-17 during March 1987 is presented (S.Upton (1987)). Again, the results of Simu89, Simu93, and Wellsim are shown. It is noted that the best fittings to the measured data were obtained with Simu89, Simu93, and Wellsim.

5. RESULTS

Obtaining fairly good results, SIMU93 has been used for different Reservoir and Production Engineering purposes, one of which is its application in the Los Azufres Geothermal Field during the second semester of 1992. In order to iritall a 5 MW tubo-generator unit, Well A-26 was opened for evaluation at that time. A cold water input into the 9 5/8" pipe was detected, at an approximate depth of 400 m (total length 1084 m). To avoid the introduction of this cold water, which was impeding the flow into the well, several solutions were proposed. The most favourable solution given by SIMU93 call for the installation of a 7" pipe at a depth of 300 to 500 m. According to SIMU93 results the mass flow rate would be reduced to 15%. After the installation of the pipe the well was reopened and the mass flow rate showed a reduction of 15%.

On the other hand, Simu93 has been compared with other wellbore simulators and the results in Figs. 1 and 2 showed its ability in the reproduction of flowing pressure profiles.

In addition, the method presented here to estimate two-phase three component ($NaCl-H_2O-CO_2$) flow rates has been applied to the published data of Karamakar and Cheng (1980), The following deviations were detected: an error within 6% when its results are compared with those of James' Method, for the case of pure water; an error between -5 and 15% for gas/gas+steam ratios between 0 and 0.17; and errors between -7 and 10% for the NaCl concentrations between 0 and 4.28 Mol NaCl/kg H_2O.

FIG.1 WELL AZ-18 MARCH, 1986

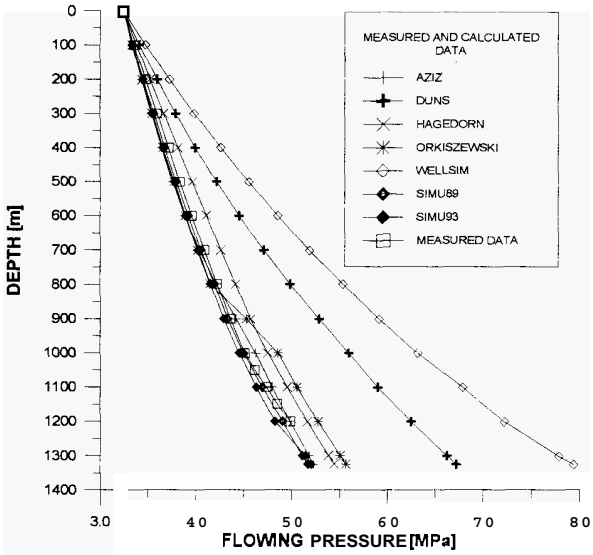
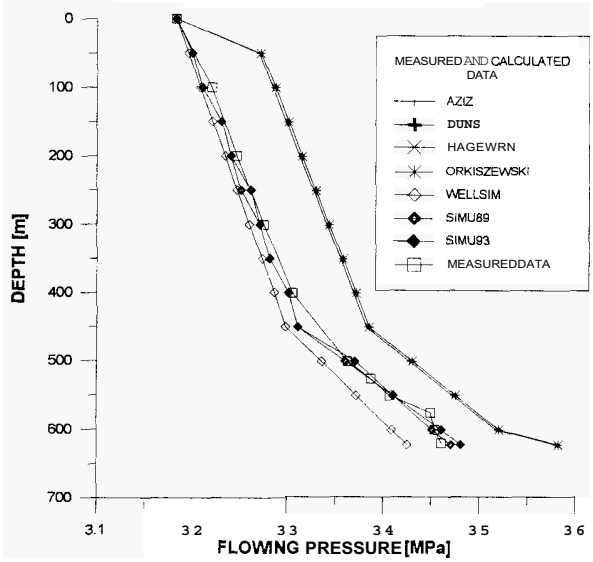


FIG.2 WELL AZ-17 MARCH, 1907



6. CONCLUSIONS

The conclusions of the study are as follows:

1. The calibration of this kind of wellbore simulator is usually made by comparing the results of the model with the measurement of flowing pressure and temperature logs running throughout the well. Therefore, the main support for the calibration of any wellbore simulator is the assurance of the measurements, inside and outside the well.

2. SIMU93 seems to give good results in most of the cases where it is applied. However, it could be prudent to test this wellbore simulator under more general conditions with a greater sampling of data (i.e. pressure and temperature logs, production data, and geochemical data).

3. SIMU93 has been compared with the commercial wellbore simulator Wellsim. In specific cases, some correlations included in Wellsim gave very different values than those measured inside the well. This fact indicates that care needs to be taken in the use of wellbore simulators.

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APPENDIX

I. SIMU93'S FUNDAMENTAL EQUATIONS

The Fundamental Equations for the case of an Adiabatic-One Dimension-Steady State flow employed in the computational program are the following

I.1 Momentum-Mass Equation.

$$P_1 = P_2 + 10^{-6}\left[\frac{f_C\, L\, G^2(v_1+v_2)}{4\, D_H} + \frac{2\, g\, L\, \cos(\phi)}{v_1+v_2} + G^2\,(v_2-v_1)\right] \quad (1)$$

where:

P = absolute pressure [MPa]
f_C = Colebrook-White friction factor [Dimensionless]
G = total mass velocity [kg/m^2-s]
L = pipe length [m]
v = specific volume of the mixture [m^3/kg]
D_H = hydraulic pipe diameter [m]
$COS(\phi)$ = cosine of the angle formed by the wellbore and the axis lying on the direction of the gravitational force [Degrees]
g = local gravitational acceleration [m/s^2]

subindex

1 = referred to pipe cross-section number one
2 = referred to pipe cross-section number two

The numbers of the cross-sections depend on the direction of calculus not on the flow direction.

1.2 Energy-Mass Equation

$$h_1 = h_2 + 0.0005\left[G^2\,(v_2^2 - v_1^2) + g\, L\, \cos(\phi)\right] \quad (2)$$

where:

h = specific enthalpy of mixture [kJ/kg]

1.3 Auxiliary Equations

The specific volume of the mixture is defined by

$$v = v\,(P,h) \quad (3)$$

and the friction factor is calculated by using the Colebrook-White correlation

$$\frac{1}{\sqrt{f_C}} = 0.8686\, L_N\left(\frac{1}{R_R}\right) + 0.8686\, L_N\left(1 + \frac{9.28}{R_R\, R_{e_D}\sqrt{f_C}}\right) = 1.14 \quad (4)$$

where:

R_R = pipe's relative roughness [Dimensionless]
$L_N(x)$ = natural logarithm of argument x
R_{eD} = Reynolds Number based on pipe diameter [Dimensionless]

and the Reynolds Number is defined by

$$R_{e_D} = \frac{4\, m}{\pi\, D_H\, \mu} \quad (5)$$

where:

m = total mass flow rate [kg/s]
μ = dynamic viscosity of mixture [Pa-s]
π = 3.1416

II. MASS FLOW RATE EQUATION

The empirical equation developed by Russell James to evaluate geothermal producing wells can be written as (S. Upton (1991))

$$m_t = \alpha_{RJ}\, P^{0.96}\, h_O^{-1.102} \quad (6)$$

where:

m_t = mass flow rate [kgls]
α_{RJ} = 13172136.63 d^2
d = internal pipe diameter at the discharge section [m]
P = lip or critical pressure [MPa]
h_O = fluid stagnation enthalpy [kJ/kg]

The Equation developed in this work which takes into account the presence of Carbon Dioxide and Sodium Chloride is

$$\alpha_{RJ}\, P^{0.96}\, h_O^{-1.102}\left[\delta\, h_t - \alpha_G\, h_{CO_2,g} - h_{H_2O,g}\right] - m_{H_2O,l}\,\delta\,(\alpha_N\, h_{NaCl} + \alpha_l\, h_{CO_2,l} + h_{H_2O,l}) - m_{H_2O,l}\,\gamma\,(\alpha_G\, h_{CO_2,g} + h_{H_2O,g}) = 0 \quad (7)$$

where:

$$\gamma = \alpha_N + \alpha_L + 1 \qquad \delta = \alpha_G + 1 \quad (8)$$

$$\alpha_N = \frac{\beta_{NaCl}}{1-\beta_{NaCl}} \qquad \alpha_L = \frac{\alpha_{Cl}}{1-\alpha_{Cl}} \qquad \alpha_G = \frac{\alpha_{Cg}}{1-\alpha_{Cg}} \quad (9)$$

$$\beta_{NaCl} = \frac{58.4428\ \hat{\upsilon}}{1000 + 58.4428\ \hat{\upsilon}} \quad (10)$$

where

β_{NaCl} = mass fraction of sodium chloride in a liquid water-sodium chloride solution [Dimensionless]
$\hat{\upsilon}$ = Sodium chloride concentration in the brine [Mol NaCl/kg of H_2O]

$$\alpha_{Cl} = \frac{m_{CO_2,l}}{m_{H_2O,l} + m_{CO_2,l}} \quad (11)$$

where

α_{CL} = mass fraction of liquid CO, in a liquid H_2O-CO_2 solution [Dimensionless]
$m_{CO2,l}$ = mass of liquid CO, in the solution [kg]
$m_{H2O,l}$ = mass of liquid H_2O in the solution [kg]

$$\alpha_{Cg} = \frac{m_{CO_2,g}}{m_{H_2O,g} + m_{CO_2,g}} \quad (12)$$

where

α_{CG} = mass fraction of gaseous CO, in a gaseous H_2O-CO_2 mixture [Dimensionless]
$m_{CO2,g}$ = mass of liquid CO, in the solution [kg]
$m_{H2O,g}$ = mass of liquid H_2O in the solution [kg]