PRESSURE AND DENSITY MEASUREMENTS OF SELECTED FLUID-BEARING ZONES AT THE WASTE ISOLATION PILOT PLANT (WIPP)

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ABSTRACT

A field effort is presently being conducted at the Waste Isolation Pilot Plant (WIPP) to collect accurate pressure and density information from the Culebra and Magenta dolomite members of the Rustler formation. The spatial variation of fluid density that occurs in these water-bearing units requires the use of numerical models to accurately solve for flow direction and velocity. The groundwater regime is a vital element in possible release scenarios of radionuclide-bearing fluid from the repository.

Field tests were conducted on four wells utilizing a testing apparatus composed of two pressure and temperature monitoring systems and a point water sampler. Pressure versus depth plots are linear with a correlation coefficient of 0.999 or greater. Comparison of the calculated density and measured density of water obtained at depth agree within 2 percent of density measurements obtained after continuous pumping of the formation for several days before sampling. The temperature gradients ranged from 0.4° to 0.6°C per 100 feet. The data presented here are preliminary and serve as developmental information for the detailed operating plan currently under preparation.

INTRODUCTION

Determination of groundwater flow direction and velocity is difficult if spatial variation in fluid density exists across a flow regime.[1,2,3] In such a case, it becomes necessary to utilize a sophisticated numerical model to determine flow direction and velocity. Such models require accurate downhole fluid density and pressure measurements and accurate elevation control obtained from as many wells as possible.

Obtaining accurate formation pressure and density measurements is difficult in deep geologic test wells.[4] Variables such as well construction, well contamination, elevation control, and instrument calibration affect the accurate collection of data and its usefulness in determining flow directions and velocities. Standard pressure monitoring equipment available from the oil industry has accuracy and resolution limitations. Thorough evaluation of this equipment is required before confidence can be obtained in its usefulness for application to nonideal flow systems which occur at the WIPP site. This paper describes the field effort being undertaken to obtain accurate and well-documented pressure and density information from both the Culebra and Magenta members of the Rustler formation.

BACKGROUND

The Waste Isolation Pilot Plant (WIPP) is a research and development facility to demonstrate the safe disposal of radioactive waste. This facility, operated by the Department of Energy, is located 25 miles east-southeast of Carlsbad, New Mexico. It is proposed that transuranic waste generated by the Department of Defense be buried in bedded salt approximately 2150 feet below the surface.

The WIPP site is located within the Pecos Valley section of the southern Great Plains physiographic province.[5] Geologically, the site is located in the northern portion of the Delaware Basin, one of the westernmost sedimentary basins collectively known as the Permian Basin. Approximately 13,000 feet of Permian strata are present in the Delaware Basin,[6] including thousands of feet of evaporite sequences composed in part of halite, anhydrite, and gypsum.

The most significant water-bearing units in the area of the WIPP site are the Culebra dolomite and Magenta dolomite members of the Rustler formation. The hydrology of these units is important because they provide the most likely conduits for flow of radionuclide-bearing fluid to the accessible environment in the event of a breach of the facility.[7]

The Culebra is 20- to 30-feet thick and is approximately 700 feet below the land surface near the center of the WIPP site. The Culebra dips gently (about 2 degrees) in an easterly direction.[5] In the vicinity of the WIPP site, water in the Culebra varies from nearly fresh to brine. The total dissolved solids ranged from 3200 mg/l to 420,000 mg/l.[7] This results in a significant variation in the fluid density. Previously reported densities range from 1.001 g/cc to 1.178 g/cc.[7]

THEORETICAL APPROACH

One approach used to correct for variations in density is to convert observed head values to equivalent fresh water head. However, this method is incapable of providing precise flow directions or rates.[1]

For aquifers such as the Culebra that exhibit spatial variation of density, the concept of hydraulic head is invalid. A fluid potential does not exist in this case.[2] It is necessary to resort to a more fundamental representation of the fluid properties:

$$h = P/\rho g + z \qquad (1)$$

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where P is the fluid pressure, ρ is the fluid density, g is the acceleration due to gravity, and z is the elevation above the datum. Darcy's law is therefore expressed as

$$\underline{q} = \frac{\underline{k}}{\mu} \nabla \left[P + \rho g z \right] \tag{2}$$

where $\underline{q}$ is the specific discharge, $\underline{k}$ is the intrinsic permeability, μ is the dynamic viscosity, and ∇ is the gradient operator. In order to determine flow velocities and directions, a numerical model written in terms of fundamental parameters is required. Such a model has the following governing equation:

$$\nabla \cdot \left(\frac{\underline{k}}{\mu} \nabla \left[P + \rho g z \right] \right) = \rho g \phi c_T \frac{\partial}{\partial t} \frac{P}{\rho g} \tag{3}$$

where ϕ is the porosity, and c_T is the bulk total compressibility.

As can be seen, accurate formation pressure and density values are required to solve Eq. (3). To obtain these parameters, we take advantage of the incompressible form of the hydrostatic fluid equation:

$$\partial p / \partial z = -\rho g \tag{4}$$

which can be integrated to

$$\rho = -\Delta p / g \Delta z \tag{5}$$

A pressure transducer can be utilized to obtain pressure measurements at numerous known depths in the borehole. Eq. (5) indicates that a plot of pressure versus depth should produce a straight line whose slope is equal to the product of density and the acceleration due to gravity. If such a plot deviates from a straight line, density stratification in the borehole is implied.

METHODOLOGY

Four wells were selected for a preliminary field survey with a pressure/density testing device. The device consisted of a combination quartz pressure transducer and thermistor temperature sensor, a strain gage pressure transducer, a second separate thermistor temperature sensor, and a downhole water sampling probe. Two separate pressure and temperature measuring devices were used for comparison during the initial phase of testing.

The combination quartz-based pressure transducer and temperature system was manufactured by Seling Corp. and has an advertised accuracy of +/- 1.5 psia and +/- 0.6°C and resolution to 0.15 psia and 0.6°C. The strain gage-based pressure transducer system, manufactured by Enviro-Labs, Inc. (from here on referred to as Enlabs), has an advertised linearity of 1.25 psig. The thermistor temperature probe, also manufactured by Enlabs, has an advertised accuracy of +/- 0.3°C and resolution to 0.1°C. The water sampling probe collects approximately 250 cc of water under formation pressure using a clock-actuated valving device. The probe is designed such that no contamination of the water sample occurs upon retrieval.

An initial field testing procedure was established as follows. After performing initial surface checks of the equipment, the testing device was lowered into the well to the fluid surface. The well was then logged in selected increments for temperature and pressure to the bottom of the formation. Depth was indicated by a counting device mounted on the reel assembly. Distances to the formation were obtained from published reports.[8,7,9] The assembly was then withdrawn from the well, the clock set on the water sampler, and the assembly was again lowered into the well to collect the water sample. The water samples were collected near the center of the formation being tested.

RESULTS

The objectives of the initial field survey were: to determine the accuracy, resolution, and stability of the pressure transducers and temperature thermistors; to evaluate the mechanical functioning of the equipment and accuracy of the depth measuring device; and to become familiar with software used on the surface computer controllers. The testing program is in its initial stages and a detailed operating plan, complete with calibration procedures, is currently being developed. No corrections have been made for influences due to well construction or possible sample contamination. Until the operating plan is in effect and proper quality control procedures established, the data presented here are preliminary and are not definitive or final.

Well H-05b

Test well H-05b is located northeast of the WIPP site (Fig. 1) and is completed in the Culebra dolomite. The Culebra interval is from 899 to 922 feet below top of casing (BTOC) and has a reported transmissivity of 0.2 feet squared per day.[7] The total depth of the hole is 925 feet. Four months prior to conducting the pressure/density survey the well was pumped continuously for nine days. This was in conjunction with the ongoing Water Quality Sampling Program. A packer was installed during this pumping 22 feet above the top of the Culebra. A total of 1560 gallons of water was removed during the water quality sampling.

The static water level was measured at 485.2 feet BTOC at the time of the survey. From the static water level, readings were taken every 25 feet to the top of the Culebra, and then the top, middle, and bottom of the Culebra were logged. Figure 2 is a plot of pressure versus depth for both pressure transducers utilized during the survey. The offset of the two lines represents the different reference pressures of the transducers. The strain gage transducer was of the non-vented type referenced to atmospheric pressure, and the quartz transducer was referenced to absolute pressure. The plots of the two transducers are linear with the correlation coefficient for both lines equal to 0.999. The slopes of the lines are almost identical at 0.482 and 0.483.

Figure 3 shows a plot of temperature versus depth. It appears from the plot that both thermistor thermometers require time to equilibrate after being lowered into the water. After an apparent adjustment period, the Enlabs thermistor thermometer increased in a relatively smooth fashion to a depth of 800 feet with a gradient of approximately 0.5°C per 100 feet, then the gradient decreased to approximately 0.4°C per 100 feet to the bottom of the Culebra. The Seling thermistor thermometer appears

The results from the four *Culebra* wells are by no means conclusive. The pressure versus density plots for the four test wells are very linear for the most part with excellent correlation coefficients of 0.999 or greater. The agreement was, in general, very good between the two pressure transducer systems utilized, but further testing is necessary to evaluate the responses more completely. The response of the Enlabs thermistor thermometer appears much more linear than that of the Seling thermistor thermometer.

By assuming that the density values obtained during the Water Quality Sampling Program are the true values, the densities obtained from point sampling and the calculated density values using the pressure depth data agree within 2 and 1 percent respectively for the four wells surveyed. The temperature gradient ranges from 0.4° to 0.6°C per 100 feet. There was some discrepancy of the results obtained between the two thermistor thermometer systems and the two transducer systems utilized. Further testing will include strict calibration procedures to better define absolute pressure and temperature values and the linearity of the responses to most effectively correlate the measurements obtained between the different test wells. Also to be included in the reduction of the pressure and density values will be the accuracy of the elevation control when taking the measurements and noninstrumental factors such as borehole deviation, all of which need to be considered for a comprehensive error propagation analysis.

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TABLE I

Comparison of Density Values for the Four Test Wells

WELL ID	DENSITY CALCULATED g/cc	DENSITY TRUE* g/cc	DENSITY Pt. Smpl. g/cc	ERROR (True - Calc.)/True x 100 %	ERROR (True - Pt. Smpl.)/True x 100 %
H-05b	1.115	1.105	1.099	0.9	0.5
H-06b	1.039	1.042	1.022	0.3	1.9
H-08b	1.001	1.002	1.002	0.0	0.1
WIPP-26	1.007	1.007	1.012	0.5	0.5

*As determined from Water Quality Sampling Program.

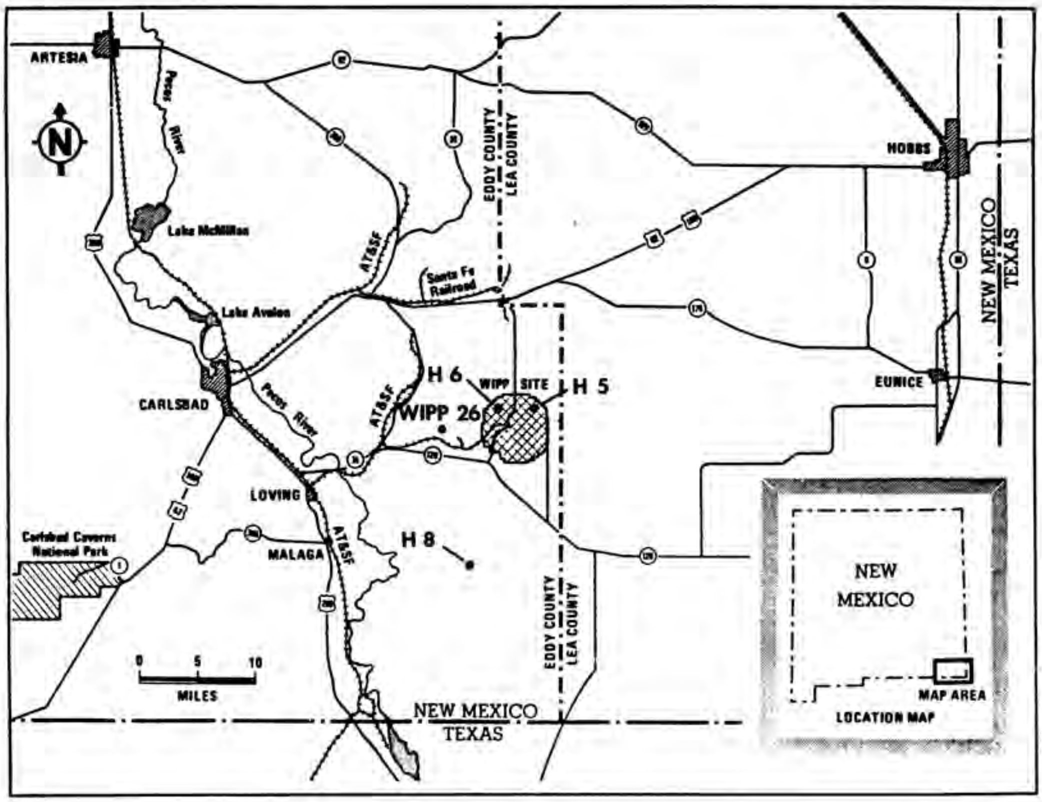

Fig. 1. Location Map of WIPP Site and Well Locations.

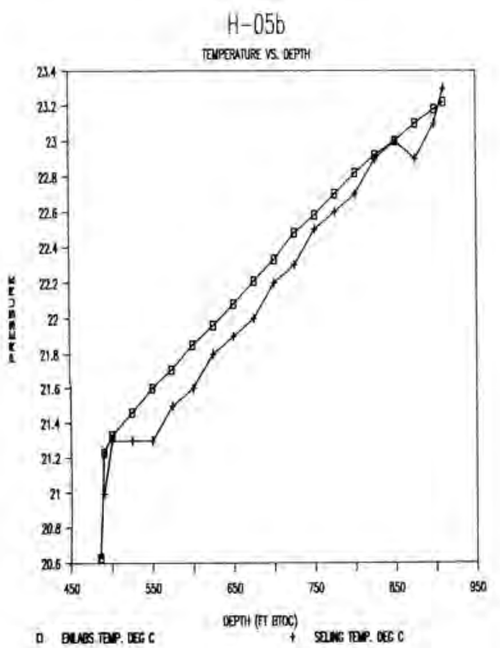

Fig. 3. Temperature Versus Depth Plot of Well H-05b.

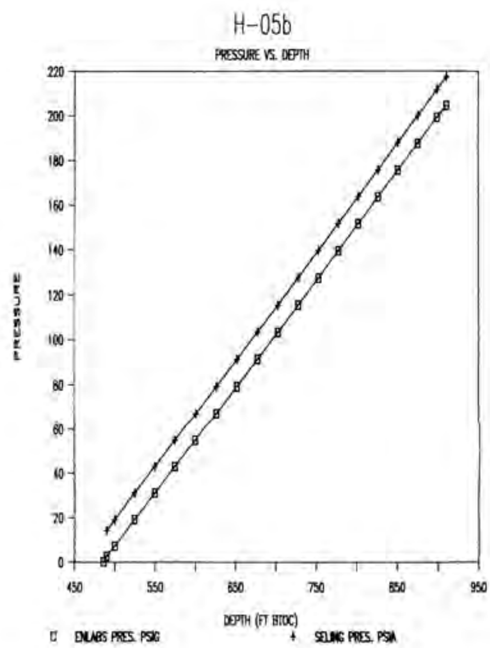

Fig. 2. Pressure Versus Depth Plot of Well H-05b.