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Contamination of Shallow Aquifers Caused by the Injection of Brines for Secondary Recovery, Pembina Oil Field, Alberta

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by

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CONTAMINATION OF SHALLOW AQUIFERS CAUSED BY THE INJECTION OF BRINES FOR SECONDARY RECOVERY, PEMBINA OIL FIELD, ALBERTA

Introduction

Water flooding operations in the Pembina Oil Field are partly carried out with oil field brines recovered elsewhere in the field; due to the highly corrosive nature of the brines and the absence of tubing in the injection wells it is highly probable that at some time the oil well casing will fail and the brine, which is under a high injection pressure will be in direct contact with the shallow fresh water aquifers in the Paskapoo Formation. The following calculations are an attempt to give an estimate of the distance the brine will move outward from the well after a certain time in a hypothetical aquifer. The calculations are based on the formula given by Walton (1962) which gives the relation between the pressure head at the well, the time t and the rate of discharge or recharge. It is further assumed that the brine completely displaces the fresh water, and the radius of the resulting cylindrical body of brine can be calculated by equating the pore volume of this body to the volume of brine recharged. The hypothetical aquifer is assumed infinite in areal extent, and nonleaky. The aquifer coefficients that were chosen are partly based on a report on the water resources of the Pembina area by Farvolden (1961) and partly on representative average values of fine to medium, partly cemented sandstone, the typical aquifer in the Paskapoo Formation. These coefficients are as follows:

Transmissibility (T):	500 U.S. gallons per foot per day;
Storage coefficient (S):	1.0×10^{-4};
Porosity (f):	10%;
Thickness (m):	100 feet.

The radius of the well bore is assumed to be 1 foot; the pressure difference between the sand face and the formation 1,100 psi or 2,540 feet of water.

Calculation of Volume of Brine Injected

The volume of water recharged into the aquifer per unit of time, at time t since injection started is given (Walton, 1962) by:

$$Q = \frac{S_w T}{229} G(\lambda) \tag{1}$$

where Q = rate of recharge (U.S. gallons per minute)

S_w = constant head at well bore (ft)

T = transmissibility of the aquifer, in U.S. gallons per foot per day

G = the well function, constant head, tables of which are given in Walton (1962)

$$\lambda = 9.29 \times 10^{-5} Tt / r_w^2 S \tag{2}$$

r_w = radius of the well bore, in feet

S = storage coefficient of the aquifer, a dimensionless quantity

On insertion of the assumed quantities in (1) we obtain:

$$Q = 5,000\ G(\lambda)$$

and in (2):

$$\lambda = 4.65 \times 10^{2} t$$

To arrive at the cumulative volume recharged, G( ) has to be found for values of t and the result integrated, or

$$Q_{total} = 5,000 \cdot \sum_{i=1}^{n} t_i \cdot G(\lambda_i)_{average}$$

The result is given in the table.

Values of t, λ, $G(\lambda)$, $\sum G.\Delta t$, R

t (minutes)	λ	$G(\lambda)$	$\sum G.\Delta t$	R (feet)
1	4.65×10^2	0.278	0.278	2.34
5	2.30×10^3	0.229	1.22	5.08
10	4.65×10^3	0.212	2.20	6.81
100	4.65×10^4	0.171	18.79	19.95
1000	4.65×10^5	0.144	154.8	57.0
10^4	4.65×10^6	0.123	1323	167.0
10^5	4.65×10^7	0.108	1.15×10^4	493.0
1.6×10^6	7.4×10^8	0.094	1.57×10^5	1820
10^7 or (20 yrs.)	4.65×10^9	0.086	9.05×10^5	4375

Calculation of the Radial Distance of the Brine Front (R)

The volume of brine recharged into the aquifer at a certain time is assumed to have fully replaced the original fresh water around the well and to occupy all the available pore space in a cylindrical body of height equal to the thickness (m) of the aquifer and its axis being the well bore. The radius of this cylindrical body can be calculated by equating the volume recharged to the pore volume of the cylinder. Pore volume of cylinder $= m\pi R^2 f = 31.4R^2$.

The volume recharged is calculated as U.S. gallons and must be converted to cubic feet. We then obtain:

$$R = \sqrt{\frac{\text{volume (gallons)}}{7.43 \times 31.4}} = \sqrt{\frac{G \quad t \times 5000}{7.43 \times 31.4}} = 4.6\sqrt{\sum G.\Delta t}$$

Values of R calculated in this manner are given in the last column of the table.

Effects of Diffusion

If consideration were given to the diffusion of the brine into the fresh water, it is clear that the zone of contamination will extend beyond the one calculated.

After a period of 20 years the radius of contamination has been calculated as 4,375 feet, or approximately one mile, corresponding to an area of about three square miles. Even if, at this time, injection ceased due to the depletion of the oil reservoir this area would in time expand due to diffusion; given an initial concentration of the original brine of 8,000 ppm, before the brine had been diluted to less than 400 ppm and was potable again, the area of contamination would have increased to approximately 60 square miles.

Remarks

The results obtained are based on a large number of assumptions and assumed values of the aquifer dimensions and aquifer constants. An endeavor has been made to obtain values characteristic of the Paskapoo Formation but the values of the storage coefficient and the porosity used are guesses based on experience with aquifers of a similar nature. Therefore, the figures obtained for the distance R in which water will be contaminated must be regarded solely as giving an indication of the order of magnitude of the distance in reality.

References

Walton, W. C. (1962): Selected analytical methods for well and aquifer evaluation, Illinois State Water Survey, Urbana, Bulletin49.

Farvolden, R. N. (1961): Groundwater resources of the Pembina area, Alberta; Research Council of Alberta, Edmonton, Alberta, Preliminary Report 61-4.

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