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HYDROLOGIC DATA REDUCTION TECHNIQUES AND UNIT CONVERSIONS FOR USE IN THE OGRE, T-WAVE, FLIP, AND RAVE FLUID FLOW CODES

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Introduction

Essentially all the hydrologic data used in the fluid flow codes come from hydrologic tests, geophysical logs and core studies. The hydrologic tests are used to determine kH, the permeability-thickness product, while logs and core studies are used to determine porosity and producing intervals in the well. The hydrologic tests consist of either drawing down the fluid level from a constant depth or at a constant rate, or injecting fluid at a constant rate and then observing the recovery rate. Results from these tests are then used to determine the kH product.

Several methods are used in analyzing these data to arrive at a kH product. The method employed here is based on a technique described by Witherspoon et al.[1] This is the method presently used at Lawrence Radiation Laboratory.

For most drawdown tests, water is "bailed" or swabbed through tubing from a constant depth for a certain length of time. During this time the swab depth, the amount of fluid removed on each swab cycle and the time are recorded.

A rough field calculation of the kH product is made after each swab cycle. These calculations can be used as an index of how long the test should be continued since the successive kH products will approach a constant value as the test progresses.

Since the swab depths are estimated by the swab unit operator and the static fluid level is determined from the subsequent recovery test, these field-calculated kH products are considered to be only approximate. Table 1 illustrates the format for collecting field data.* After the test has ended final recalculations are made using pressure and temperature bombs inserted in the well in conjunction with the production packers. Water levels at the beginning and end of each swab cycle can be calculated from the pressure data, and the fluid viscosity can be obtained from the temperature data.

The recovery following a swabbing test is monitored by logging the fluid level as a function of time. This is most commonly done with a logging unit designed by the U.S. Geological Survey (USGS) and equipped with an ohmmeter and a two-wire probe which records when the probe contacts the fluid. Both Birdwell and Schlumberger have similar tools. Fluid levels are recorded until the level has returned to near the static, or pretest,

*Tables 1 and 2 and Fig. 1 are taken from Ref. 2.

condition. This time, in most cases, is about one and one-half times that consumed during the drawdown portion of the test. Table 2 illustrates the form of the recovery data.

Table 1. GB-3 swab test No. 3.

Date: 9/1/69
Interval tested: 3580 to 3699 ft

Run No.	Clock time	$\sum \Delta t$ (min)	Staff gauge (ft)	Δq (gal)	$\Delta q/\Delta t$ (gal/min)	$\sum \frac{\Delta q}{\Delta t}$ (gal/min)	Swab depth (ft)	Water level (ft)	kH[a] (md-ft)
1	1431	0					1200	0	
2	1439	8					1500	300	
3	1453	22					1800	400	
4	1504	33					1900	550	
5	1515	44					2000	700	
6	1535	64					2100	900	
7	1546	75					2200	1000	
8	1600	89					2200	1100	
9	1613	102					2400	1200	
10	1628	117					2500	1300	
11	1638	127					2600	1500	
12	1650	139					2600	1500	
13	1715	0	0.83	0	0	0	2700	1600	
14	1730	15	1.02	111.7	7.44	7.44	2700	1650	16.59[a]
15	1745	30	1.28	152.9	10.19	17.63	2700	1650	39.32
16	1800	45	1.52	141.1	9.02	26.65	2700	1700	59.43
17	1815	60	1.75	135.2	7.84	34.49	2700	1750	76.91
18	1830	75	1.95	117.6	5.88	40.37	2700		90.03
19	1848	93	2.10	88.2	4.90	45.27	2700	1800	100.95
20	1858	103	2.29	117.7	11.17	56.44	2700	1800	125.86
21	1908	113	2.47	105.8	8.23	64.67	2700	1800	144.21
22	1920	125	2.61	82.3	7.06	71.73	2700	1800	159.96
23	1930	135	2.73	70.6	7.06	78.79	2700	1800	183.58
24	1941	146	2.85	70.6	6.41	85.20	2700	1800	190.00
25	1952	157	3.00	88.2	8.02	93.22	2700	1800	207.88
26	2002	167	3.10	58.8	5.88	99.10	2700		220.99
27	2013	178	3.25	88.2	8.02	107.12	2700	1800	238.88
28	2033	188	3.36	64.7	6.47	113.59	2700		253.31
29	2034	199	3.45	52.9	4.81	118.40	2700		264.03

[a]These values were omitted in UCRL-50812 and were replaced by refined laboratory calculations.

Table 2. GB-3 recovery test.

Date: 9/1-9/2/69
t_0 = 199 min

Clock time	Δt (min)	Water level (ft)	$\frac{t_0 + \Delta t}{\Delta t}$	Clock time	Δt (min)	Water level (ft)	$\frac{t_0 + \Delta t}{\Delta t}$
2152	78	1912	3.550	0400	446	1246	1.446
2204	90	1847	3.210	0500	506	1221	1.394
2206	92	1837	3.163	0550	556	1206	1.358
2209	95	1821	3.095	0624	590	1198	1.337
2213	99	1804	3.001	Injected 100 gal water			
2221	107	1771	2.860	0701	627	1083	1.314
2229	115	1738	2.731	0704	630	1084	1.313
2238	124	1706	2.605	0707	633	1085	1.313
2248	134	1673	2.486	0710	636	1086	1.312
2258	144	1641	2.382	0713	639	1087	1.311
2309	155	1607	2.284	0716	642	1089	1.310
2321	167	1575	2.192	0719	645	1090	1.308
2334	180	1542	2.105	0724	650	1092	1.306
2348	194	1509	2.027	0731	657	1094	1.303
0005	211	1476	1.943	0738	664	1096	1.300
0023	229	1442	1.869	0743	669	1097	1.297
0043	249	1410	1.799	0753	679	1100	1.293
0108	274	1378	1.726	0804	690	1104	1.289
0137	303	1345	1.657	0824	710	1108	1.280
0213	339	1312	1.587	0844	730	1112	1.273
0300	386	1279	1.516				

Calculation of kH

The formula used for determining kH from the drawdown data is

$$kH = \frac{\mu \Sigma \frac{\Delta q}{\Delta t}}{1.791 \times 10^{-4} \Delta H}$$

where

kH is the permeability-thickness product (md-ft),

μ is the fluid viscosity (cp),

$\Sigma \frac{\Delta q}{\Delta t}$ is the summation of the production rates (gal/min),

ΔH is the drawdown from the static head (ft), and

1.791×10^{-4} is a unit conversion factor.

The formula used for determining kH from the recovery data is

$$kH = \frac{1.151 \mu \overline{\frac{\Delta q}{\Delta t}}}{8.953 \times 10^{-5} \Delta H_{10}}$$

where

1.151 is the slope of the dimensionless pressure over dimensionless time for time sufficiently large,

$\overline{\Delta q}/\Delta t$ is the average production rate during swabbing (gal/min),

ΔH_{10} is the change in head over one log cycle of time (ft),

8.953×10^{-5} is the unit conversion factor, and

μ is the fluid viscosity (cp).

To use this formula it is necessary to construct a plot, as shown in Fig. 1, where t_0 is the time since swabbing started, Δt is the time since swabbing stopped, and H is the depth of the water. When the log of $(t_0 + \Delta t)/\Delta t$ is 1, the fluid level should be back to static conditions. Since it is often not practical to monitor the fluid levels for long times, the process may be speeded up by "slugging" the well with enough fluid to raise the level above static. With a few additional observations of the declining water level, extrapolation to $(t_0 + \Delta t)/\Delta t = 1$ will give a fairly accurate value of the static level. This level is used in the swabbing equation to determine ΔH.

To obtain ΔH_{10}, a straight line is drawn from the static level through the last few data points and extended across one log cycle. Then ΔH_{10} is the difference in water levels over one log cycle. In general, lower kH values are obtained from the recovery data than from the swab data.

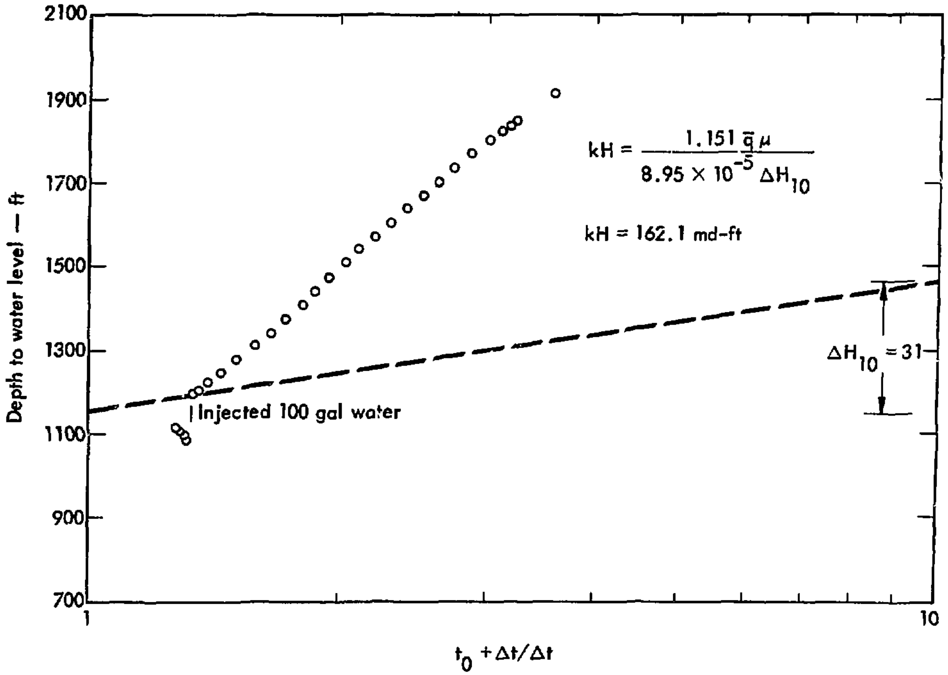

Fig. 1. GB-3 water level recovery.

Unit Conversions

In the fluid flow codes, units of permeability are used which depend on the form of the velocity equations in each code. The one-dimensional, incompressible flow codes T-WAVE,[3] RAVE,[4] and FLIP[5] are based on the following form of the velocity equation:

$$V = -\frac{k}{\phi}\left(\frac{\partial h}{\partial r}\right)$$

where

ϕ is the fractional porosity (dimensionless),

$\frac{\partial h}{\partial r}$ is the hydraulic gradient (dimensionless), and

V is the horizontal velocity (distance L/time t).

The permeability k, then, has the units of velocity, that is, distance per unit time. The usual units for T-WAVE and RAVE are ft/min, and for FLIP, ft/sec.

The form of the velocity equations in OGRE,[6] a two-dimensional, compressible flow code, is

$$V = -\frac{k}{\mu}\left(\nabla P + \nabla \gamma\right)$$

where

μ is the viscosity (mass M/distance L × time t), and

∇P and $\nabla \gamma$ are pressure gradients (mass/area × time M/L^2t^2).

The permeability k, then, has the units of area L^2. The usual units in OGRE are ft^2.

If the permeability is determined by the method outlined in the beginning of this report, it will be reported as a permeability-thickness product, or kH, in units of md-ft. By dividing this product by the effective producing thickness, a permeability in millidarcies results. This may be converted to velocity or area units by the following relationship:

1 millidarcy $= 3.171 \times 10^{-8}$ ft/sec (FLIP)

$= 1.903 \times 10^{-6}$ ft/min (T-WAVE, RAVE)

$= 1.062 \times 10^{-14}$ ft^2 (OGRE)

If the permeability is determined by the U. S. Geological Survey, Water Resources Branch, it will normally be reported as Transmissivity, T, or sometimes as Relative Specific Capacity, R_{sc}. Sometimes both values are reported in which case, as will be explained later, the use of the transmissivity value is recommended. (Transmissivity replaces the former term, Coefficient of Transmissibility.)

Transmissivity T, which is used in the field and is uncorrected for density and viscosity, is usually reported in units of gallons/day/foot of drawdown (gpd/ft). However, the USGS plans to revise its standard hydrological terminology, and T may appear in more recent data in units of $meters^2$/day.

T is defined as

$$T = Kb \qquad (1)$$

where

K is the hydraulic conductivity in gal/day/ft^2 (gpd/ft^2) or meters/day (m/day), and

b is the aquifer thickness in feet or meters.

The term Kb is similar to (but not identical with) the kH product.

Since T/b can be expressed in units of velocity, conversion of T for use in FLIP, T-WAVE, and RAVE is straightforward. The relationships are as follows:

$$\frac{T}{b}\left(\frac{gpd}{ft^2}\right) \times 9.28 \times 10^{-5} = ft/min$$

$$\frac{T}{b}\left(\frac{gpd}{ft^2}\right) \times 1.547 \times 10^{-6} = ft/sec$$

$$\left(\frac{T}{b} \; \frac{m^2}{m\ day}\right) \times 7.475 \times 10^{-3} = ft/min$$

$$\left(\frac{T}{b} \; \frac{m^2}{m\ day}\right) \times 1.246 \times 10^{-4} = ft/sec.$$

For conversion to units of area, necessary for OGRE, the following relationships hold:

$$\frac{T}{b}\left(\frac{gpd}{ft^2}\right) \times 5.180 \times 10^{-13} = ft^2$$

$$\frac{T}{b}\left(\frac{m^2}{m\ day}\right) \times 1.272 \times 10^{-11} = ft^2$$

As part of its program to revise its hydrological terminology, the USGS is abandoning the reporting of hydrologic results in terms of Relative Specific Capacity. This term evolved from the need to make short-duration recovery tests in wells on Pahute Mesa at the Nevada Test Site in connection with mining operations below the water table. The usefulness of the term is in question since it has not been shown to be applicable to any other location. Two other factors also show it to be of doubtful value: (1) groundwater flow under Pahute Mesa is largely fracture-controlled, and (2) the tests are so short (~5 min) that steady-state conditions cannot be assumed. In fact, an examination of the formula for determining R_{sc} shows that its value cannot be constant until the aquifer has almost fully recovered.

In conclusion, too many factors must be assumed to make the use of this term practical in most cases. It is recommended, then, that only data reported by the USGS in terms of Transmissivity or millidarcies be used for the fluid flow codes.

References

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