U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: AIR-PERMEABILITY TESTING - ROLE OF FRACTURES

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DETERMINATION OF UNSATURATED-ZONE GAS PERMEABILITY AND POROSITY OF FRACTURE NETWORKS

REGULATORY CONCERNS
- RELEASE OF TRITIUM, CARBON-14, ETC.
- MOVEMENT OF WATER VAPOR AND ITS IMPACT ON LIQUID WATER FLUX

GAS-FLOW MECHANISMS
- BAROMETRIC PUMPING
- TOPOGRAPHIC RELIEF
- GEOTHERMAL GRADIENT
- HEAT LOADING CAUSED BY CANISTERS
- DIFFUSION

IN SITU PNEUMATIC TESTING PROVIDES PARAMETERS FOR:
- GAS-FLOW MODELING
- TRANSIENT FRACTURE-FLOW MODELING
GAS-FLOW EQUATIONS

\[ \nabla \cdot \left[ \frac{k}{\mu} \nabla (p^2) \right] = \phi C_t \frac{\partial p}{\partial t} \]  (1)

UNDERLYING ASSUMPTIONS:

1. FLUX OF ROCK GRAINS, \( q_g \), IS NEGLIGIBLE
2. IDEAL GAS LAW APPLIES
3. GAS EXPANDS ISOTHERMALLY
4. GRAVITY'S INFLUENCE IS NEGLIGIBLE
5. FLOW IS LAMINAR
6. \( S_g = 1.0 \)
7. EXTERNAL LOAD ON ROCK IS CONSTANT

\[ k, \mu, C_p \text{ and } \beta = f(p) \]
### RANGE OF VALUES OF COMPRESSIBILITY

<table>
<thead>
<tr>
<th>Material</th>
<th>Compressibility, $\alpha$ ($\text{m}^2/\text{N} \text{ OR Pa}^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLAY</td>
<td>$10^{-6}$-$10^{-8}$*</td>
</tr>
<tr>
<td>SAND</td>
<td>$10^{-7}$-$10^{-9}$*</td>
</tr>
<tr>
<td>GRAVEL</td>
<td>$10^{-8}$-$10^{-10}$*</td>
</tr>
<tr>
<td>JOINTED ROCK</td>
<td>$10^{-8}$-$10^{-10}$*</td>
</tr>
<tr>
<td>SOUND ROCK</td>
<td>$10^{-9}$-$10^{-11}$*</td>
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<tr>
<td>WATER ($\beta$)</td>
<td>$4.4 \times 10^{-10}$*</td>
</tr>
<tr>
<td>GAS ($\beta$)</td>
<td>$10^{-5}$-$10^{-6}$</td>
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</tbody>
</table>

*FREEZE AND CHERRY (1979)
GAS-FLOW EQUATIONS

DIMENSIONLESS PARAMETERS

DIMENSIONLESS TIME \( t_D = \frac{kt}{\phi \mu C_t (r_w)^2} \)

DIMENSIONLESS RADIUS \( r_D = \frac{r}{r_w} \)

DIMENSIONLESS PRESSURE \( P_D = \frac{\pi kb(p^2 - p_w^2)T_s c}{P_s c Q_s c \mu T} \)

RADIAL FLOW EQUATION IN DIMENSIONLESS TERMS

\[
\frac{1}{r_D} \frac{\partial}{\partial r_D} \left[ r_D \frac{\partial P_D}{\partial r_D} \right] = \frac{\partial P_D}{\partial t_D} \tag{2}
\]
TCURVE. BAT

- DATA REDUCTION PROGRAM RPROG. FOR
- MAKE TYPE CURVES TMAKE.FOR
- MATCH TYPE CURVES TO EXPERIMENTAL DATA VISUALLY TMATCH.PAS
- CALCULATE STORATIVITY AND PERMEABILITY CALC.FOR
- AUTOMATED CURVE MATCHING AMATCH.FOR
SIMULATED DATA SET
\((p_f = 4.1E+05 \text{ Pa})\)

FINITE DIAMETER WELL SOLUTION
VAN EVERDINGEN AND HURST (1949)
\(r_o = 1.0, c_o = 0.0\)

\(r_o = 1.0, c_o = 5.0\)
SIMULATED DATA SET

TRUE PERMEABILITY = 0.8000E-15 m²
TRUE POROSITY (%) = 17.00

TYPE CURVE MATCHING

PERMEABILITY = 0.8046E-15 m²
POROSITY (%) = 18.24
BOREHOLE LOCATIONS
AT APACHE LEAP TUFF SITE, SUPERIOR, ARIZONA

KEY
- GROUND SURFACE
- FRACTURE LOCATION
- INTERVAL LOCATION

I = INJECTION INTERVAL
G = GUARD ZONE INTERVAL
N = LOCATION OF FLOW TEST
#N OBSERVATION ZONES

LOCAL Z COORDINATE (M)

LOCAL X COORDINATE (M)

BOREHOLE Y2

BOREHOLE Z2
EXPERIMENTAL DATA FILE:
A:CFLOW8D.DIF

THEIS (1935)

WELL TEST DATA

SPHERICAL FLOW
EXPERIMENTAL DATA FILE: A:CFLOW8D.DIF

LOG10 (ELAPSED TIME (SEC))

LOG10 (pD)

LOG10 (tD/rD^2)

LOG10 ((pD^2 - pD0^2) (Pa^2))

- WELL TEST DATA

THEIS (1935)

SPHERICAL FLOW
RADIAL FLOW MODEL

<table>
<thead>
<tr>
<th>PERMEABILITY</th>
<th>0.3248E-1 m²</th>
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<tr>
<td>POROSITY (%)</td>
<td>123.20</td>
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SPHERICAL FLOW MODEL

<table>
<thead>
<tr>
<th>PERMEABILITY</th>
<th>9.767E-13 m²</th>
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<tbody>
<tr>
<td>POROSITY (%)</td>
<td>7.26</td>
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