SATM - Version 1.4

Saturation Modelling

PURPOSE

"SATM" sheet: This spreadsheet uses some different methods to determine the capillary pressure vs. water saturation relationship. The output plots show the relationship and how accuracy they are graphically.

"Sat-height" sheet: using zonation results from ORZ and endpoints from PROPS/CP2 to generate the saturation-height relationship by applying Modified Carman-Kozeny-Purcell (MCKP) method.

Input Data

"SATM" sheet

- *The user select tab "SATM" to start using the program.*
- *The user click on "Import" to import the dataset from prepared datasheet to SATM.*
- *At any time, the user can click on the "Reset" button to start over the calculation.*

"Sat-height" sheet

- *The user needs to use Copy-Paste Special to fill in the input table.*
- *All the mandatory input boxes colored in green must be checked and filled in correctly before proceeding next steps.*

WORKFLOW

The following methods are implemented in SATM version 1.4. Details of calculation steps can be found in the "Literature" section.

1. *Modified Carman-Kozeny-Purcell (MCKP)*
2. *Leverett-J function*
3. *Lamda function*
4. *Modified Brooks-Corey*
5. *Johnson*
6. *Skelt-Harrison*
7. *Thomeer*
8. *Desouky*

Calculation and fitting with Preliminary Analysis (PA)

- Click on "PA" button to bring up the Preliminary Analysis window.
- Select one method (or all method) and fitting options then click on "Preliminary Analysis" button.
- The desired method will be calculated and displayed on the plot. Its fitting results quality, reflected by R2, will be displayed.

Once the calculation finished, the user can use "Zoom" option to zoom-in the plot.

There are 03 options for PA in this version. More options will be added in next versions.

Manual Fit and Auto Fit require more work and data. These functions will be considered to implement.

Generating saturation-height relationship

The sheet "Sat-height" uses MCKP method to generate the saturation-height relationship of the well.

To compare the generated sat-height curve with the Sw/So log or resistivity log, the user can copy the logs and superposition the generated sat-height curve having transparent background format.

Literature

Refer to lectures/presentations for all methods. Below are some brief information:

1. Modified Purcell method (2006)

Using CPI vs. ESG approach. Best fit is obtained for each curve and can be used for regression later.

$$ESG=\frac{\emptyset S_w}{1-\emptyset S_w}$$

$$CPI=0.0314\sqrt{\frac{1/P_c^{\ 2}}{\emptyset S_w}}$$

$$CPI = aESG + b$$

$$P_c=\frac{0.0314}{CPI\sqrt{\emptyset S_w}}$$

- Input: P_c, ϕ, S_w
    - Calculate ESG and CPI using formulas above
    - Use least square method to determine a and b, R^2 can be used to improve the fit
    - Calculate P_c from S_w with new fitted CPI

2. Leverett J-function method (1941)

Using J-function and draw best fit line relating Sw and J. There are several variations/improved version of Leverett-J.

$$J(S_w)=\frac{P_c}{\sigma\cos\theta}\sqrt{\frac{k}{\varphi}}$$

$$J=a(S_w)^b$$

- Input: P_c, k, ϕ, σ, $\cos\theta$
    - Calculate $J(S_w)$
    - Determine a and b by using least square method, R^2 can be used to improve the fit
    - Calculate S_w from P_c

3. Lambda function method

Lambda is a function of porosity and Sw is a function of lambda. The two functions are solved by optimization method (RMSE).

- Input: P_c, S_w
- Convert P_c to h for each pressure point
- Calculate λ , C and d by RMSE method
- With obtained λ, C and d, calculate S_w from P_c

4. Modified Brook-Corey method (1966)

$$S_{eff}=\frac{S_w-S_{wir}}{1-S_{wir}}$$

$$S_{eff}=\left(\frac{P_c}{P_e}\right)^{-\lambda}$$

- Input: P_e, P_c, S_{wir}, S_w
    - Calculate S_{eff}
    - Calculate λ by using least square method
    - With obtained λ calculate S_w from P_c

5. Johnson method (1987)

Sw as a function of k and Pc. The best fit is obtained in 2 steps by using averaging k (centroid k) then applied for whole k range.

$$\log(S_w)=BP_c^{-C}-A\log(k)$$

- Input: P_c, k, S_w
    - Use $S_w = bk^A$ to calculate A, b by using least square method, then calculate $\bar{A}$ (A average)

- Pick a centroid $k_{centroid}$ and calculate S_w' for each P_c using $\log S_w' = A\log k_{centroid} + \log b$
- Use S_w' and $\bar{A}$ to obtain B' in $\log B' = \log S_w' - \bar{A}\log k_{centroid}$
- Use $B'=B*P_c^C$ to determine B and C by using least square method
- Use Johnson's equation to calculate S_w from P_c

6. Skelt-Harrison method (1995)

Sw is a function of Pc by using 4 fitting parameters A, B, C, D in the equation:

$$S_w = 1 - A\exp\left(\frac{B}{P_c + D}\right)^C$$

- Input: P_c, S_w
  - Use Solver (in Excel) to calculate A, B, C, D for each plug
  - With obtained A, B, C, D, calculate S_w from P_c

  Best fit is obtained easily for each plug but the regression for field values will be limited.

7. Thomeer method (1960)

$$\frac{(V_b)_{P_c}}{(V_b)_{P_\infty}} = e^{-\frac{G}{\log\left(\frac{P_c}{P_d}\right)}}$$

$$S_w = A - (1 - S_{wir}) * e^{-\frac{G}{\log\left(\frac{P_c}{P_d}\right)}}$$

- Originally for mercury injection data
  - Modified for other lab methods
  - Input: P_c, P_d, k, S_w
  - Calculate G by iteration and estimate A
  - Use modified equation to calculate S_w from P_c

8. Desouky method

RQI = FZI*$\emptyset_n$ (1) where RQI = $\sqrt{\frac{K}{\emptyset}}$ (2) $\emptyset_n = \emptyset/(1-\emptyset)$ (3)

(1) and (2) => FZI*$\emptyset_n$= $\sqrt{\frac{K}{C}}$ (4)

$J(S_w) = \frac{P_c}{\sigma \cos\theta}\sqrt{\frac{K}{\emptyset}}$ (5)

(4) and (5) => $J(S_w) = \frac{P_c}{\sigma \cos\theta}$ FZI*$\emptyset_n$ (6)

For a constant pore geometry system (i.e fixed value of FZI):

$J(S_w) = J^* * S_{wn}{}^{-1/\lambda}$ (7) where $S_{wn} = \frac{S_w - S_{wr}}{1-S_{wr}}$ (8)

Substituting (7) into (6): $P_c = \frac{\sigma \cos\theta * J^* * S_{wn}{}^{-1/\lambda}}{FZI*\emptyset_n}$ (9)

- Calculate RQI and fn from core data using (2) and (3)
- Plot RQI vs. fn on log-log plot, FZI is the intercept of the unit slope line with coordinate fn = 1.
- Calculate J-function and Swn using (5) and (8)
- Plot the values of J-function vs. Swn on log-log scale to determine J* and l.
- Pc is calculated by using (9).