Petrophysical functions

Includes following topics:

1. Porosity calculation
2. Porosity calibration
3. Permeability calculation
4. Water saturation calculation
5. Water resistivity calculation
6. Creating a petrophysical report
Petrophysical functions in CycloLog

CycloLog includes a number of basic petrophysical functions. Introductory instructions for these are given in this section of the Tutorial Manual. Functions covered here are:

- Porosity calculation
- Porosity calibration using core measurements
- Permeability calculation
- Water saturation calculation
- Water resistivity calculation
- Creating a petrophysical report

Porosity calculation

In CycloLog, there are three different options for estimation of porosity, starting from the following logs:

- Density log
- Sonic log
- Density and neutron logs

You may wish to use more than one of these methods, depending on which logs are available, and to compare the results.

The three options are selected from the Porosity menu:

- Click on the Petrophysics menu at the top of the screen;
- Move the cursor to the Porosity item;
- Select the required method.
Porosity calculation from a density log

Calculation of porosity ($\phi_{\text{density}}$) from a density log uses the following formula:

$$\phi_{\text{density}} = \frac{\rho_{\text{matrix}} - \rho_{\text{bulk}}}{\rho_{\text{matrix}} - \rho_{\text{fluid}}}$$

where,
- $\rho_{\text{matrix}}$ = matrix (or grain) density
- $\rho_{\text{bulk}}$ = bulk density as measured by the logging tool
- $\rho_{\text{fluid}}$ = density of fluid

So, as long as we can provide numbers for the matrix density ($\rho_{\text{matrix}}$) and the fluid density ($\rho_{\text{fluid}}$), this formula will give us the porosity from the density log ($\rho_{\text{bulk}}$).

If the lithology of the matrix is known, use the following standard density values (in g/cm$^3$):
- Sandstone (quartz) 2.648
- Limestone (calcite) 2.710
- Dolomite 2.850
- Gypsum 2.351
- Anhydrite 2.977
- Halite 2.032

For the fluid density, use 1.0 g/cm$^3$ for freshwater, and 1.1 g/cm$^3$ for brine.

Alternatively, the matrix density can be obtained directly from the log data, as explained below.
To start the calculation:

- Go to the Petrophysics menu at the top of the CycloLog screen;
- Select Porosity;
- Select Use Density Log;
- The following dialogue box opens:

   ![Calculate porosity using the density](image)

- Check that the correct well is selected;
- Select the required density log from the drop-down list;
- Specify the depth interval over which the porosity is to be calculated;
- Enter the Fluid density (in g/cm³);
- EITHER enter the Matrix density (if known);
- OR estimate the Matrix density from the data as follows:
  - Click on the Histogram icon next to the Matrix density box:
The histogram is interactive;

- To enter the required value into the porosity formula:
  - Hold the cursor over the value regarded as representing the appropriate density value, and click once with the left mouse button;
  - A vertical red line marks the currently selected value;
  - Click OK to enter this value into the Matrix density box in the Calculate porosity dialogue box;

- Click OK to run the porosity calculation.

CycloLog runs the calculation and creates a new log called **Porosity RHOB** that is saved to the workspace.
Porosity calculation from density and neutron logs

The second method available in CycloLog calculates porosity from a combination of a density log and a neutron density log. The combined porosity ($\phi_{N-D}$) is calculated as the root-mean-square of the porosities from the neutron and density logs separately:

$$\phi_{N-D} = ((\phi_N^2 + \phi_D^2) / 2)^{1/2}$$

If the lithology of the matrix is known, use the following standard density values (in g/cm$^3$):

- Sandstone (quartz) 2.648
- Limestone (calcite) 2.710
- Dolomite 2.850
- Gypsum 2.351
- Anhydrite 2.977
- Halite 2.032

For the fluid density, use 1.0 g/cm$^3$ for freshwater, and 1.1 g/cm$^3$ for brine.

Alternatively, the matrix density can be obtained directly from the log data, as explained below.

To start the calculation:

1. Go to the Petrophysics menu at the top of the CycloLog screen;
2. Select Porosity;
3. Select Use Density and Neutron Log;
4. The following dialogue box opens:
Check that the correct well is selected; 
Select the required **Density** log from the drop-down list; 
Select the required **Neutron** log from the drop-down list; 
Specify the depth interval over which the porosity is to be calculated; 
Enter the **Fluid density** (in g/cm$^3$); 
EITHER enter the **Matrix density** (if known); 
OR estimate the **Matrix density** from the data as follows: 
  o Click on the **Histogram** icon next to the **Matrix density** box:
The histogram is interactive;
- To enter the required value into the porosity formula:
  - Hold the cursor over the value regarded as representing the appropriate density value, and click once with the left mouse button;
  - A vertical red line marks the currently selected value;
  - Click **OK** to enter this value into the **Matrix density** box in the **Calculate porosity** dialogue box;
- Click **OK** to run the porosity calculation.

CycloLog runs the calculation and creates a new log called **Porosity RHOB-NPHI**, shown in the following illustration beside the original density and neutron (RHOB, NPHI) logs:
Porosity calculation from a sonic log

Porosity ($\phi_{\text{sonic}}$) may also be calculated from a sonic log if no density log is available, although the results may be less reliable. The calculation is based on the following formula:

$$\phi_{\text{sonic}} = \frac{\Delta t_{\log} - \Delta t_{\text{matrix}}}{\Delta t_{\text{fluid}} - \Delta t_{\text{matrix}}}$$

where,

- $\Delta t_{\log}$ = sonic log value (interval transit time)
- $\Delta t_{\text{matrix}}$ = interval transit time for the matrix
- $\Delta t_{\text{fluid}}$ = interval transit time for the fluid
Given values for the interval transit time in the matrix and the pore fluid, this formula allows us to calculate sonic porosity from the values of the sonic log.

If the lithology of the matrix is known, you may be able to use one of the following standard values (in μs/ft) for $\Delta t_{\text{matrix}}$:

- Sandstones (quartz) $55.5 - 51.0$
- Limestone (calcite) $53 - 47.6$
- Dolomite $43.5$
- Gypsum $52 - 53$
- Anhydrite $50$
- Halite $67.0$

For the fluid interval transit time, use 189 μs/ft for freshwater-based mud, or 185 μs/ft for saltwater-based mud.

Alternatively, the matrix interval transit time can be obtained directly from the log data, as explained below.

To start the calculation:

- Go to the Petrophysics menu at the top of the CycloLog screen;
- Select Porosity;
- Select Use Sonic Log;
- The following dialogue box opens:
Check that the correct well is selected;
Select the required **Sonic** log from the drop-down list;
Specify the depth interval over which the porosity is to be calculated;
Enter the **Fluid interval transit time** (in μs/ft);
**EITHER** enter the **Matrix interval transit time** (if known);
**OR** estimate the **Matrix interval transit time** from the data as follows:
  - Click on the **Histogram** icon next to the **Matrix interval transit time** box:
The histogram is interactive;

- To enter the required value into the porosity formula:
  - Hold the cursor over the peak regarded as representing the appropriate sonic value, and click once with the left mouse button;
  - A vertical red line marks the currently selected value;
  - Click OK to enter this value into the Matrix interval transit time box in the Calculate porosity dialogue box;

- Click OK to run the porosity calculation.

CycloLog runs the calculation and creates a new log called **Porosity DT**, shown in the following illustration beside the original sonic (DT) log:
Porosity calibration

If direct porosity measurements are available (from core samples, for example), these can be used to calibrate a log-derived porosity curve.

Suppose that the following porosities have been measured, at the given depths:

<table>
<thead>
<tr>
<th>Depth</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>3618m</td>
<td>0.072</td>
</tr>
<tr>
<td>3650m</td>
<td>0.175</td>
</tr>
<tr>
<td>3700m</td>
<td>0.135</td>
</tr>
<tr>
<td>3708m</td>
<td>0.265</td>
</tr>
</tbody>
</table>
➢ Go to the Petrophysics menu and click Calibrate Porosity;
➢ In the dialogue box that opens, select the porosity log to be calibrated;
➢ Click Next;
➢ The following dialogue box opens:

![Calibration with Core Plug Porosities](image)

➢ Enter the depths and the core porosity measurements in the first and second columns;
➢ *(Alternatively, if you have the values in a table like the one above, copy it to the clipboard, and click the Import button to paste the values into the dialogue box)*;
➢ Click Calculate, and CycloLog enters the porosity values from the selected log;
➢ *(You can choose either to Interpolate between the values at the nearest depths, or Shift to nearest, to use the log value at the nearest available depth)*;
➢ Click Next;
A graph of **Core Porosity** against **Log Porosity** opens, in which the black line shows the non-calibrated relationship, and the red line shows the relationship as calibrated with the core porosity measurements;

The regression equation for the calibrated relationship is shown;

Use the **Print** and **Export** buttons to print the graph, or to export it as a graphics file.

If the graph is acceptable, click **Finish** to apply the calibration to all the points in the porosity log;

The calibrated log appears in the Workspace as (for example) **Porosity RHOB-NPHI-calibrated**.
**Permeability calculation**

Calculation of permeability in CycloLog requires (1) a porosity log, and (2) some core permeability measurements.

The steps are the same as for **Calibrate Porosity**, above. That is:

- ➢ From the Petrophysics menu, select Permeability;
- ➢ In the Calculate Permeability dialogue, select the porosity log to be used (and the depth interval, if relevant);
- ➢ Click Next;
- ➢ In the Permeability dialogue box, enter the depth and permeability for each available core permeability measurement;
- ➢ Click Calculate to find the corresponding log porosity values;
- ➢ Click Next;
- ➢ The graph and regression equation show the resulting relationship between core permeability and log porosity: if this is acceptable, click Finish;
- ➢ CycloLog applies the equation to all log values (in the specified depth interval) and creates a new log called (for example) Permeability from Porosity RHOB-NPHI.

**Water saturation calculation**

Calculation of water saturation in CycloLog requires (1) a porosity log, and (2) the formation resistivity curve (or a deep resistivity log).

To run a water saturation calculation:

- ➢ Go to the Petrophysics menu and select Water Saturation, then Water Saturation again;
- ➢ The Calculate Water Saturation dialogue box opens:
The box shows the formula used to calculate water saturation.

- Under Interval, enter the top and bottom depths of the interval for which the calculation is to be run;
- Select the Formation resistivity log to be used;
- Select the Porosity log to be used;
- Either accept the default values for the Tortuosity factor, Cementation exponent, Water resistivity, and Saturation exponent, or enter your preferred values;
- Click OK;
- CycloLog calculates the new log, which appears in the Workspace with the name Water Saturation Curve.
**Water resistivity calculation**

Calculation of water resistivity in CycloLog requires (1) a porosity log, and (2) the formation resistivity curve (or a deep resistivity log).

To run a water saturation calculation:

- Go to the Petrophysics menu and select Water Saturation, then Water Resistance Curve;
- The Calculate Water Saturation dialogue box opens:

  ![Water Resistivity Curve dialog box](image)

- Under Interval, enter the top and bottom depths of the interval for which the calculation is to be run;
- Select the Formation resistivity log to be used;
- Select the Porosity log to be used;
- Either accept the default values for the Tortuosity factor, and Cementation exponent, or enter your preferred values;
- Click OK;
- CycloLog calculates the new log, which appears in the Workspace with the name Water Resistivity Curve.
Generate petrophysical report

The Petrophysical Report function in CycloLog can be used to generate a Net:Gross report, or other similar types of report.

The report can be generated for a total interval, or the total interval can be subdivided, the subdivisions being based on a pre-defined set of either Breaks (see CycloLog Tutorial Manual part 5), or Reservoirs (see CycloLog Tutorial Manual part 11).

To generate a Petrophysical Report:

- Go to the Analysis menu at the top of the screen, and select Report;
- The Generate Report dialogue box opens:
In the example illustrated, the analysis will look for all depths in the Porosity RHOB-NPHI log for which the value is greater than or equal to 0.15.

- Specify the interval for the analysis;
- Click on the top line under the word Log, to reveal a drop-down list;
- Select the log to be analysed;
- Click under Operator and select the operator to be used (>=, meaning greater-than-or-equal-to, in the example illustrated);
- Under Value, enter the target value (0.15 in the example);
- Click Report;
- The following window opens:
This shows the results of the analysis: for the specified depth interval, the criterion \textbf{Porosity \geq 0.15} is satisfied in 58.217m out of the total of 170m, with an average net:gross of 0.203 in the net interval.

- Click \textbf{Save} to save these results to a file, then
- Click \textbf{Close} to close the report window.

The \textbf{Generate Report} dialogue also offers a \textbf{Generate Log} button. This generates a simple log in which the value 1 indicates that the condition (e.g. Porosity \geq 0.15) is satisfied at that depth, and 0 indicates that it is not satisfied. The log is added to the Workspace, and is called \textbf{Report Log}.

This log can be used, for example, to colour a GR log to show the intervals in which the porosity is greater than 15%. (Open the GR log, right-click over the GR log display, select \textbf{Display}, then \textbf{Colour With}, then select the \textbf{Report Log}.)