State-of-the-art software for K & N correlation to generate capillary pressure curves under different wettability conditions

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Core samples obtained while drilling are usually not true representative of the reservoir due to invasion of mud filtrate. Invasion can lead to wettability alterations affecting the capillary pressure. So to have a capillary pressure data which is true representative of the reservoir, set of correlations has been developed, capable of generating the curves at any wettability, when the laboratory data at any wettability condition(s) is known. To ease the use of developed set of correlations, software has also been developed by accomplishing state-of-the-art programming in Visual Basic.

Key words: capillary pressure, wettability, wettability alterations, programming, software

1. Introduction

Capillary pressure experimental data can be generated by using Brooks and Corey[2] correlation, which can be given as[4,1]:

$$P_c(S_{em}) = p_d S_{em}^{-\frac{1}{\lambda}} \quad (1)$$

where, threshold pressure (p_d), is the pressure at which the displacement of one fluid by another will start and effective mobile phase saturation (S_{em}) for drainage process can be given as:

$$S_{em} = \frac{S_{mphase1} - S_{rmphase1}}{1 - S_{rmphase2} - S_{rmphase1}} \quad (2)$$

While for imbibition process it can be given as:

$$S_{em} = \frac{S_{mphase1} - S_{smphase1}}{1 - S_{rmphase2}} \quad (3)$$

where, the selection of phase 1 and 2, depends on for which phase the capillary pressure curve is required to be generated (in this study oil has been taken as phase 1).

2. Correlation for capillary pressure estimation

Khurram and Nawi (K & N) correlation was modified to overcome the limitation that capillary pressure data at fully or very strongly water wet ($\theta = 0°$) condition should be known. K & N correlation in its modified form, to predict capillary pressure at any wettability condition, can be given as:[6]

$$P_{c.est} = p_{db.c}(S_{em})^{-1/\lambda} \pm k_1(\Delta\theta) \cdot p_{db.c} \cdot (S_{em})^{-1/\lambda} \quad (4)$$

where, $P_{d_{b.c}}$ $p_{d_{b.c}}$, is the displacement pressure of the base case, which is experimentally determined at any known wettability. This can be best accomplished by using Amott-Harvey test or USBM method.[1,3,7] k_1 is a constant which is generally equal to 1.24×10^{-4} and $\Delta\theta$, represents the absolute difference of wettability condition in terms of contact angle between the base case and the condition at which capillary pressure data need to be generated. Contact angle of the base case in the developed correlation can be obtained with the help of experimentation (displacement tests[1,3]) and then using the following transformation:

$$\theta = \cos^{-1}(W.I.) \quad (5)$$

In general, the sign convention in the capillary pressure estimation correlation (eq.4) will be positive if the displaced phase wettability increases. The selection of effective mobile phase saturation as given in eq.(2) and (3) to be incorporated into eq.(4) for capillary pressure estimation, depends on the flow stage[6] occurring (depends on the saturation of the displaced phase) during the displacement process.

3. State-of-the-art Software for Capillary Pressure Estimation

For generating capillary pressure curves by using the developed set of K & N correlations in a time efficient manner, software has been developed using Visual Basic. The developed state-of-the-art software is capable of generating P_c data and as well as provides options to export the generated results in a form, which can be opened by using any well known applications and can also be incorporated "as it is", in any reservoir simulator, for reservoir simulation studies.

Total saturation change is divided into 20 intervals for increased accuracy during programming. So the maximum saturation change for each step can go up to

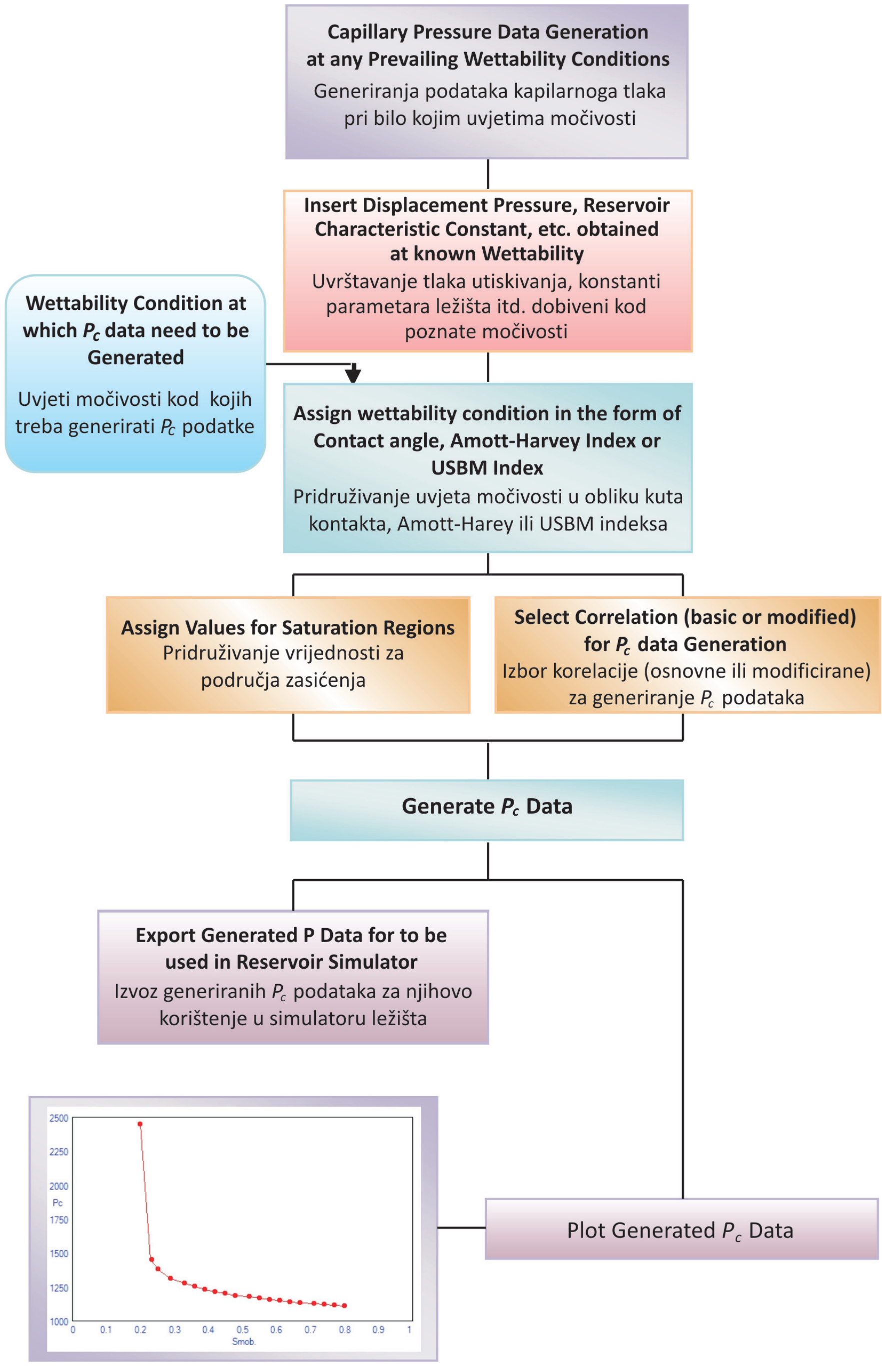

Fig. 1. Flow chart for Capillary Pressure data Generation using State-of-the-art Software
Sl. 1.

0.0526, if the total saturation change is 1 in the porous medium, which means that only one phase is present before displacement. Also no residual saturation of the displaced phase exists in the porous medium at the end of displacement process.

The programming has been done, making it possible to generate capillary pressure data at any wettability condition(s) in the sequential steps as explained with the help of flow chart given in Fig. (1) and the snapshot of the software (P_c Estimator) is shown in Fig. (2).

Figure 1 & 2 shows that any number of curves can be generated by using the following experimental data as input:

- Base case wettability
- Characteristic constant
- Displacement pressure of base case

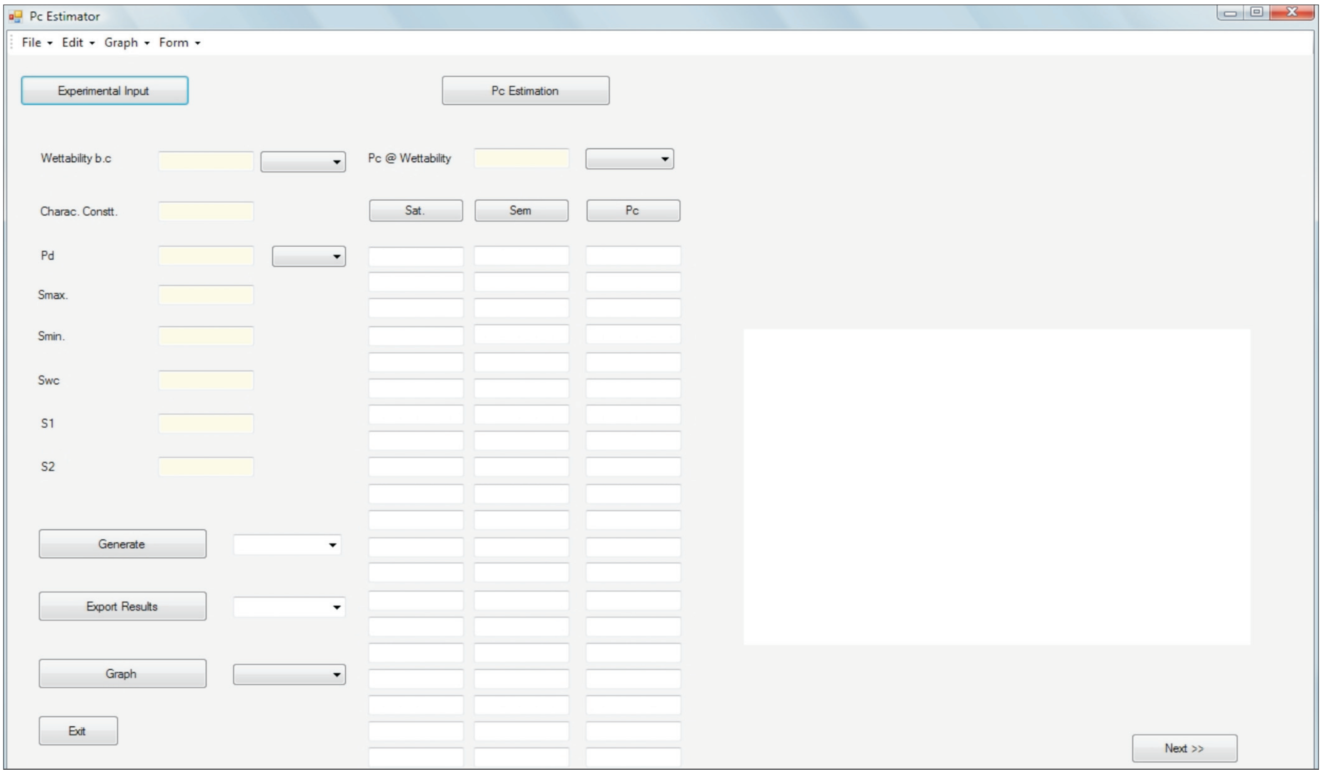

Fig. 2. Layout of P_c Estimator
Sl. 2.

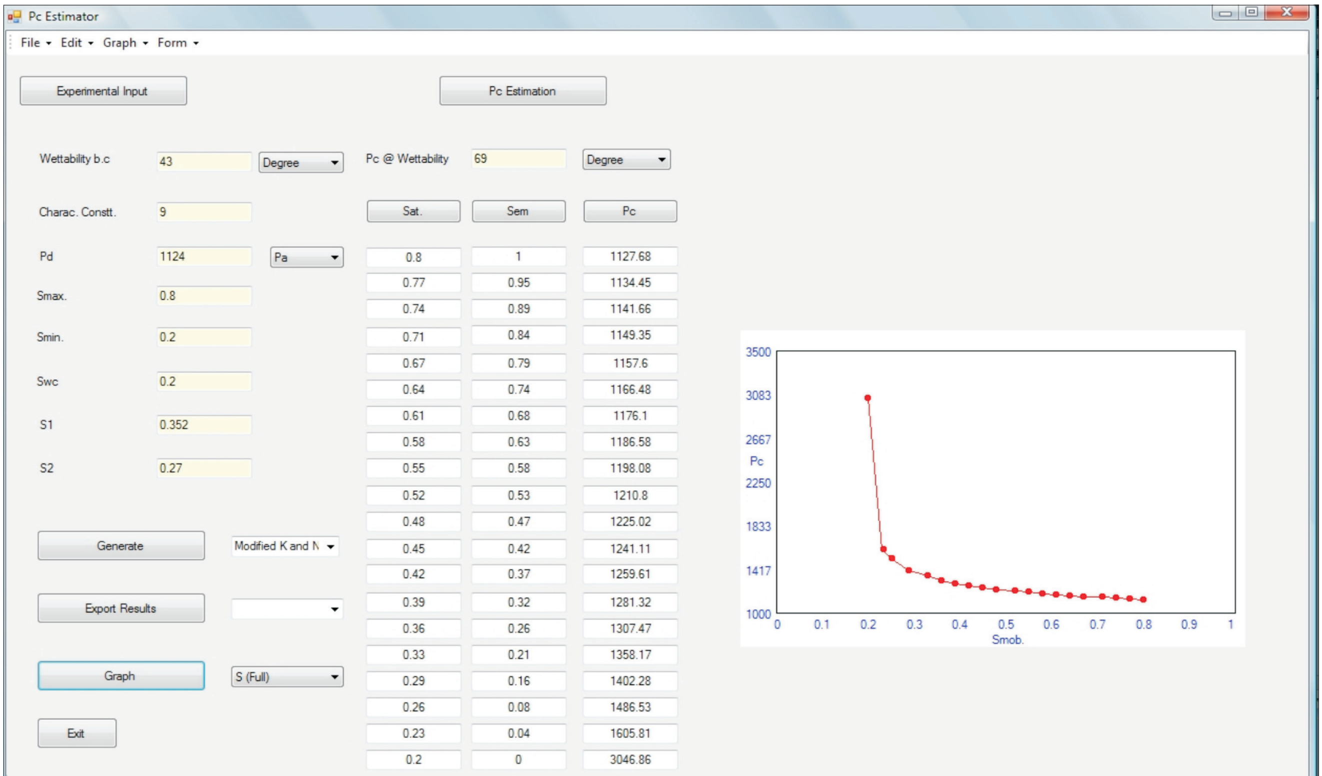

Fig. 3. Capillary Pressure data Generated by P_c Estimator
Sl. 3.

- Minimum and maximum saturation of the displaced phase
- Initial or residual saturation of second phase, if present before the displacement process is initiated
- Starting of different saturation stages

Generated capillary pressure curve using the software is shown in Figure 3.

4. Discussion and conclusion

Programming provides good means of having one time solution to complex solutions, though also providing the provisions to update the coding as new modifications has been done either in the correlations or in the algorithms. Using this methodology, capillary pressure data at any wettability condition can be generated, using the experimental data as base case. Thus overcoming the disadvantages caused by core contaminations. The generated data can be used as an input in any reservoir simulator for improved history match, based on which better knowledge of wettability and capillary pressure existing within the reservoir can be obtained.

Nomenclature

P_c	Capillary pressure
$P_{c.est}$	Estimated capillary pressure
p_d	Displacement pressure
$p_{db.c}$	Base case displacement pressure
S_{em}	Effective saturation of mobile phase
$S_{mphase1}$	Mobile phase saturation of fluid 1
$S_{rmphase1}$	Residual mobile phase saturation of fluid 1
$S_{rmphase2}$	Residual mobile phase saturation of fluid 2
$W.I.$	Wettability index
θ	Angle of contact
$\Delta\theta$	Difference in contact angle
λ	Characteristic constant

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