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Research Article

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Application of Fuzzy Logic for Pseudo Skin Estimation for Horizontal wells within Various Drainage Areas

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Abstract

Horizontal wells are becoming widely used for primary and enhanced oil recovery operations compared to vertical wells as a result of their higher productivity due to large wellbore section exposed to the reservoir which is necessary for both fluids production and injection operations.

In this work a new application related with using of fuzzy logic in the field of petroleum engineering was introduced to develop pseudo skin shape related factor to calculate and estimate the productivity of pseudo steady state horizontal wells. We can use fuzzy logic in order to determine the pattern and relationship between data set where this pattern may not be clearly known or there is no mathematical relationship among them. Prediction of introduced model has been tested against known model (Bahadori 2012 model) that developed a simple model of pseudo skin factor for horizontal well located within rectangular and square drainage areas [1].

After training the model by using 2000 data set, it was successfully to estimate the pseudo skin shape related factor by testing the model by using 1000 data set. Results indicate that the introduced model has an excellent agreement with values that have been obtained by using Bahadori 2012 model with average absolute deviation being less than 2.05%.

Sensitivity study was used by investigate different cluster values ranging from (0.3 – 0.7) to determine which is yield the lowest average calculation error. Furthermore, trend analysis showed that there is excellent agreement between this model and Bahadori 2012 model in the general trend.

Introduction

Horizontal wells are becoming widely used for primary and enhanced oil recovery operations compared to vertical wells as a result of their higher productivity due to large wellbore section exposed to the reservoir which is necessary for both fluids production and injection operations.

The productivity of the horizontal well highly affected by the pseudo-steady state skin factor for centrally located well within various drainage areas, as the pseudo-skin factor increases the productivity of a horizontal well will decrease; as consequence, its estimation method must be highly accurate and less complicated. The system parameters such as reservoir boundaries, anisotropy, well length and location of the well within the reservoir may considerably impact on the estimation of pseudo steady state skin factor.

The flow behaviour resulting in existence of five possible flow regimes

- Early radial flow regime,
- Early linear flow regime,
- Late pseudo radial flow regime,
- Late linear flow regime,
- Pseudo-steady state flow regime.

The late pseudo radial flow takes into account the pseudo-skin depends on system geometry.

This work presents a development for methods used to estimate shape-related skin factor for horizontal wells within various drainage areas. Transient pressure analysis is required to anticipate the productivity of horizontal wells.

Analysis of Transient pressure conducted to horizontal wells supposed to be more sophisticated than its counterpart in the vertical wells as result of the following troubles:

- The majority of horizontal wells models suppose that horizontal wells are completely horizontal and are in parallel to the upper and lower reservoir boundaries. Generally, the process of drilling horizontal wellbores is scarcely horizontal, since it is associated with more divergence and difference in the perpendicular plane over the length of the well.
- Computation is considered to be more complicated as result of that the horizontal wells offer negative skin factors.
- Sometimes it is sophisticated to assess the exact productivity

length of horizontal wells.

As a result of advance technology that related with using Fuzzy logic in field of petroleum engineering implementations determining and estimating petro-physic property, stimulation candidate criteria, production optimization and completion and multilateral design can be achievable.

Using of Fuzzy Logic in Petroleum Industry

In 2003 fuzzy logic has been used in order to deal with different completion scripts which might seemed to be mysterious. Selection criteria were settled to use it in multilateral technology with its implementation in a specialized regulation which enables completion engineers to design best favourable wells arrangement and completion [2].

In 2007 This same principals and techniques have utilized to understand the pattern among the given groups in such cases that many times there is no available obvious or a known mathematical relationship exists, so a new application of fuzzy logic and neural network was introduced to estimate fluid viscosity [3].

Worth mentioning in 2007, using of fuzzy logic started to be more familiar, as result of employing it in the permeability modelling to calculate permeability from log data that comes from wire line in a carbonate reservoir located in Middle East. To determine whether a specific wire line log is adequate to be an input so that it can be used in fuzzy logic modelling, coefficient was utilized to act like selection criteria. Furthermore, their estimations were considering having a superior correspondence with permeability data acquired from cores [4].

Two different fuzzy models were used in 2010 - local linear Neuro fuzzy models (LLNFM) and Adaptive Neuro Fuzzy Inference system (ANFIS) - and counter weighted by Multi-Layer Perceptron (MLP) and available empirical correlations so, the two-phase inflow performance of horizontal well were estimated [5].

Statement of the problem

One of the significant parameters affecting flow rate in horizontal production wells is the pseudo skin factor. Pseudo skin factor calculation is complicated due to the difference in the well length, reservoir length, reservoir width, reservoir thickness and well position. To overcome this difficulty, scientists came up with different flow correlations to estimate the value of the pseudo skin factor, those correlations are applicable within certain conditions and their accuracy degrades outside their design boundary range.

Objectives

The ultimate objective of this study is to develop a highly accurate and easily technique by using fuzzy logic, which could be used to calculate the pseudo skin factor which represents a main input for calculating the horizontal wells productivity, to achieve this main goal the following objectives are specified:

1. To identify the parameters those are mostly affect the shape related skin factor.
2. To develop an accurate estimation of shape related skin factor with low absolute average deviation by using fuzzy logic.

Methodology

The shape related pseudo skin factors are computed depending on the distribution of pressure response along the pseudo-radial flow regime which is controlled and affected by a set of parameters such as the location of the well within the boundaries of reservoir, reservoir size and anisotropy. In order to accomplish the main objective of this project which is to build shape related skin factor model by using fuzzy logic concept, firstly we analyze these parameters in order to identify and determine which has the most significant impact in the pseudo-radial flow period.

Consequently, we conclude that the parameters are highly affected on fluid flow inside the reservoir: involve well length, reservoir height, reservoir width, well location within reservoir and the anisotropy of reservoir which represents the horizontal and vertical permeabilities of the reservoir.

Regarding the well radius, it does not have any impact on the pressure derivative response however it is clear that reservoir length has impact in the pressure derivative response, but it just affects the late linear flow period rather than the pseudo radial flow period.

Model assumption

This model was derived based on the following assumptions:

1. The horizontal well is located in a homogeneous reservoir of rectangular or square drainage area.
2. The flow is slightly compressible with constant viscosity.
3. The horizontal well length L is parallel to upper and lower boundaries.
4. Pressure gradients are very small and the effect of gravity is negligible.
5. The horizontal and vertical permeabilities are not identical
6. The well is considered to be line source.
7. The horizontal well has infinite-conductivity and it is located in a bounded reservoir.

Fuzzy logic

The term fuzzy means something unknown, uncertainty or something that is not defined very well. There are many physical properties in the nature can be represented by non-crisp term such as cold, hot, strong, bright, etc.

Sometimes there are many problems related with petroleum engineering which are mysterious, however even the measured data is not precise to justify the use of numbers.

Fuzzy logic provides a language with syntax and semantics to translate some input data and determine the number of rule, shape and number of membership function and even the rules itself which models the behaviour of input data according to the objective output results. Fuzzy logic provides a way to compute with word.

Fuzzy logic inference system can be represented in three layers as it shown in figure 1.

- The first layer related to input variable
- The second layer apply the fuzzy rule by identifying the suitable membership function
- The third layer illustrate the output variable

The treatment of the data is achieved through many layers. Each layer is connected to the second layer by numbers of nodes and each interface between nodes connects fibers weighted by a sum.

The first layer has the same length of the input; the nodes within each next layer sum their input, identify the pattern of the relationship between the data set and produce output and possible type of functions. The final layer generates the output of the system in order to determine the weight and the pattern of relationship. Firstly, training of network by supplying it by their corresponding output, evaluating the output and then alter the weight in a specific manner to produce more accurate output. It continues to train the inputs multiple time until the error between the output of the fuzzy logic system and the real output is below a known tolerance level.

Then testing of the fuzzy logic system by supplying it inputs without outputs

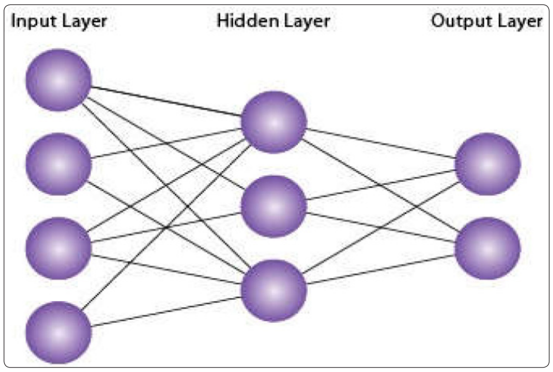

Figure 1: Fuzzy Logic Inference System layers.

Data generation

In order to generate a representative data, we used Bahadori 2012 model that developed a simple model of pseudo skin factor for horizontal well located within a rectangular and square drainage areas. The values of skin have been obtained from this model showed it has a small average deviation (less than 1%) from the real data reported in the literature so that this model is considered to be more accurate and less complicated when it used to account for the pseudo skin factor.

Bahadori correlated the length of horizontal well over drainage area side ($\frac{L}{2xe}$) with Dimensionless length (L_D) for rectangular and square drainage area for different shape with ratios of x_e/y_e of 1, 2 and 5 to predict the pseudo-skin factor. After developing his model, he concluded the following set of equations (equation (1) to equation (5)):

$$\ln(S_{CAh}) = a + \frac{b}{L_D} + \frac{c}{(L_D)^2} + \frac{d}{(L_D)^3} \qquad \text{Equation 1}$$

Where

$$a = A_1 + B_1\left[\frac{L}{2x_e}\right] + C_1\left[\frac{L}{2x_e}\right]^2 + D_1\left[\frac{L}{2x_e}\right]^3 \qquad \text{Equation 2}$$

$$b = A_2 + B_2\left[\frac{L}{2x_e}\right] + C_2\left[\frac{L}{2x_e}\right]^2 + D_2\left[\frac{L}{2x_e}\right]^3 \qquad \text{Equation 3}$$

$$c = A_3 + B_3\left[\frac{L}{2x_e}\right] + C_3\left[\frac{L}{2x_e}\right]^2 + D_3\left[\frac{L}{2x_e}\right]^3 \qquad \text{Equation 4}$$

$$d = A_4 + B_4\left[\frac{L}{2x_e}\right] + C_4\left[\frac{L}{2x_e}\right]^2 + D_4\left[\frac{L}{2x_e}\right]^3 \qquad \text{Equation 5}$$

Parameter range

Matlab software was used to generate a set of 3000 random data point of the parameters which are supposed to be the main factors impacting the pseudo skin factor, the data generated in this work have the ranges reported in Tables (1) to (3) below.

Table 1: The Generated Date Ranges for Case of *xe*/*ye* = 1.0

Parameter	Minimum Value	Maximum Value
Well Length (ft)	512	8677
Pay Zone Thickness (ft)	5.927	14.495
Horizontal Permeability (md)	4.975	190.615
Vertical Permeability (md)	0.4975	19.0615
Reservoir Length (ft)	452.5	8885.5
Reservoir Width (ft)	452.5	8885.5

Table 2: The Generated Date Ranges for Case of *xe*/*ye* = 2.0

Parameter	Minimum Value	Maximum Value
Well Length (ft)	11.52	345.6
Pay Zone Thickness (ft)	5.927	14.495
Horizontal Permeability (md)	4.975	190.615
Vertical Permeability (md)	0.4975	19.615
Reservoir Length (ft)	452.5	8885.5
Reservoir Width (ft)	226.25	4442.75

Table 3: The Generated Date Ranges for Case of *xe*/*ye* = 5.0

Parameter	Minimum Value	Maximum Value
Well Length (ft)	11.52	345.6
Pay Zone Thickness (ft)	5.927	14.495
Horizontal Permeability (md)	4.975	190.615
Vertical Permeability (md)	0.4975	19.615
Reservoir Length (ft)	452.5	8885.5
Reservoir Width (ft)	90.5	1777.1

In order to predict the shape related skin factor (S_{CAH}) with fuzzy logic our model was tested against the measured shape related skin factor [1]. The input layer here represents the parameters those are highly affected on the shape related skin factor (the parameters and their ranges considered for this study were summarized in Tables (1) to (3)) the output layer represents the measured values of pseudo skin factor which are calculated based on Bahadori 2012 model.

The data set was divided into two divisions; training data and testing data. Training input and output data are used in order to determine and discover the pattern and the relation between input and output data. The testing input data set was then used to generate a new output data based on the developed functions. The generated output data set was then compared with the data calculated using Bahadori 2012 model.

Fuzzy logic functions

Generation of fuzzy inference system structure for this model was based on three basic functions (*anfis*, *genfis2* and *evalfis*).

Model optimization

After testing several cluster radii within range (0.3 – 0.7) it was found that the optimum cluster radius is 0.4which produce the lowest average calculation error for the case of xe/ye =1 of 1.3% and 1.437% for both testing and training data respectively. For case of xe/ye = 2 the lowest average calculation error is 1.49% and 1.75% for both testing and training data respectively. While the lowest average calculation error for case xe/ye = 5 of 1.76% and 2.978% for both testing and training data respectively as shown on figure 2 and 3.

The next table summarizes the error calculation for the three cases:

Table 0: Average, Maximum and Minimum Error for Three Cases

	Case 1 (X_e/Y_e=1)			Case 2 (X_e/Y_e=2)			Case 3 (X_e/Y_e=5)		
Data type	Max error %	Min error %	Avg error %	Max error %	Min error %	Avg error %	Max error %	Min error %	Avg error %
Training data	12.5	4.4×10^{-4}	1.3	10	1.7×10^{-3}	1.49	27.1	3.9×10^{-3}	1.76
Testing data	10.8	5.04×10^{-3}	1.43	21	2.57×10^{-3}	1.75	23.3	7.21×10^{-4}	2.97

Pseudo skin results

In this part, three different cases with different reservoir length to width ratios of 1, 2 and 5 were considered. For this reason, 66.7 % of the data were used as training data sets where 33.3 % were considered as testing data set.

Case 1: (*Xe/Ye*) = 1

Figure 2 below shows the cross plot of the measured and estimated pseudo skin values from training and it shows that all the data point lain around 45-degree line. Since the minimum, maximum and average errors for this case are 4.421×10^{-4}%, 12.53 % and 1.3 % respectively, there is excellent agreement and consistency between the measured and estimated values of skin.

Figure 3 below shows the cross plot of the measured and estimated pseudo skin values from testing data set and it shows that all the data point lain around 45-degree line. Since the minimum, maximum and average errors for this case are 5.04×10^{-3}%, 10.8 % and 1.43% respectively, there is excellent agreement between the measured and estimated skin.

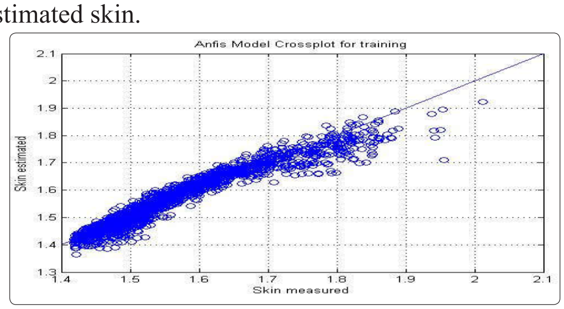

Figure 2: Anfis Model Crossplot for Training Data Set for Case *xe/ye* = 1.

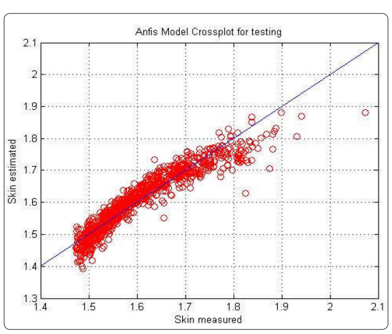

Figure 3: Anfis Model Crossplot for Testing Data Set for Case *xe/ye* = 1.

Trend analysis

The trend analysis was carried out to check the physical behaviour of the developed antis model for this purpose the pseudo skin was calculated by changing one of the parameters under study while maintaining the other constant. In this part of the work the effect of the change of the well length, pay zone thickness, horizontal permeability, vertical permeability, reservoir length and reservoir width were determined and plotted on figures.

The following figures illustrate how the behaviour of change of the well length, pay zone thickness, horizontal permeability, vertical permeability, reservoir length and reservoir width versus pseudo skin and its show that the general trend of the data set against pseudo skin generated based on Bahadori 2012 model is same as the general trend of data set against pseudo skin generated based on our study.

Figure 4 and figure 5 show that the effect of different pay zone thickness on the value of pseudo skin factor and it could be concluded from it, that as the pay zone thickness increases the pseudo skin factor will also increase.

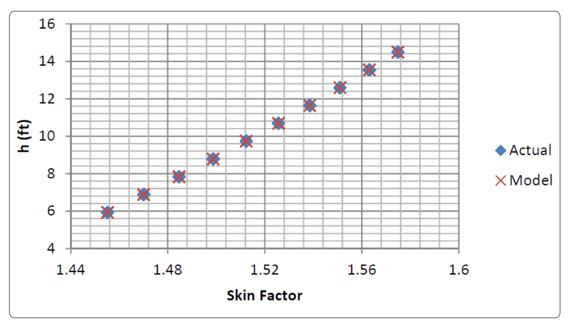

Figure 4: Trend of training data of pay zone thickness versus skin

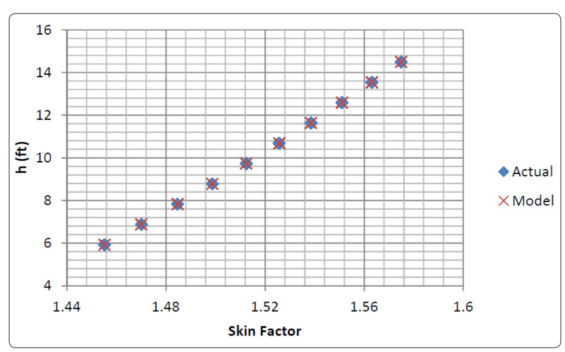

Figure 5: Trend of testing data of pay zone thickness versus skin

Figure 6, figure 7, figure 8 and figure 9 show that the effect of different horizontal and vertical permeabilities on the value of pseudo skin factor and it could be concluded from it that the horizontal and vertical permeability have no any effect on pseudo skin factor, this due to that the pseudo skin factor state is only controlled and affected by the location of the well within the boundaries of reservoir.

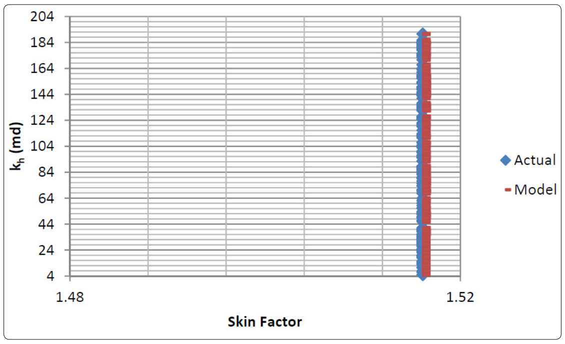

Figure 6: Trend of training data of horizontal permeability versus skin

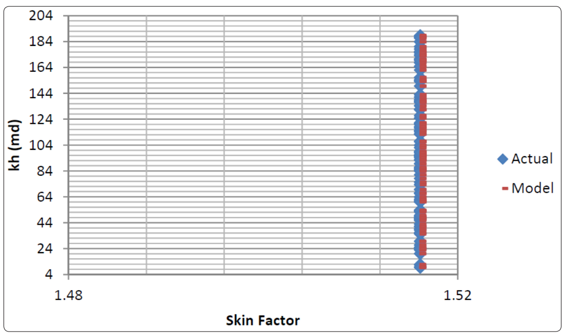

Figure 7: Trend of testing data of horizontal permeability versus skin

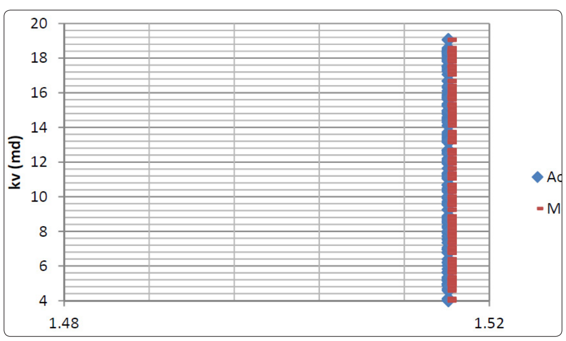

Figure 8: Trend of training data of vertical permeability versus skin

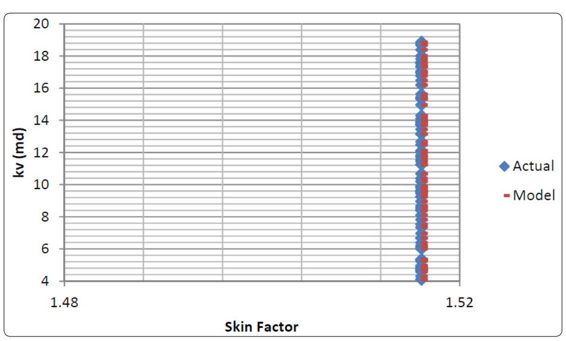

Figure 9: Trend of testing data of vertical permeability versus skin

Figure 10 and figure 11 show that the effect of different well length on the value of pseudo skin factor and it could be concluded with that as the well length increases the pseudo skin factor will decrease until reach the optimum value of well length and after then the pseudo skin factor will begin to increase. This because at the beginning of flow of fluid the pressure drop will be very small until the effect of reservoir boundaries is detected. This off course helps to determine the optimum well length and eliminate any extra cost associated with long wellbore section such as drilling and completion cost.

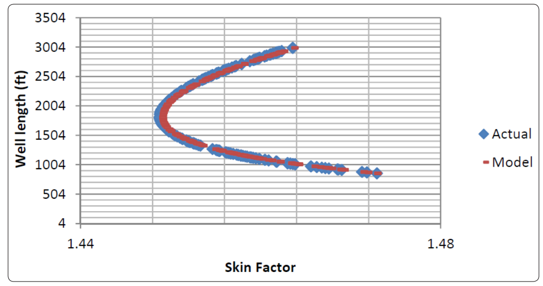

Figure 10: Trend of training data of Well length versus skin

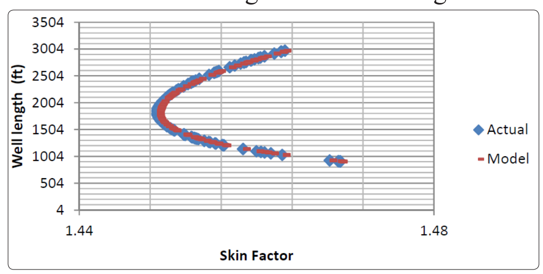

Figure 11: Trend of testing data of Well length versus skin

Figure 12, figure 13, figure 14 and figure 15 show that the effect of different reservoir length and width on the value of pseudo skin factor and it could be concluded with that as the reservoir length and width increase the pseudo skin factor will decrease.

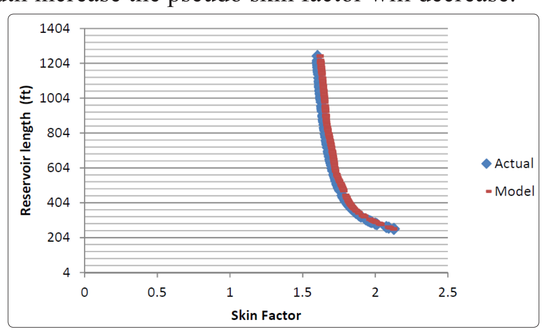

Figure 12: Trend of training data of Reservoir length versus skin

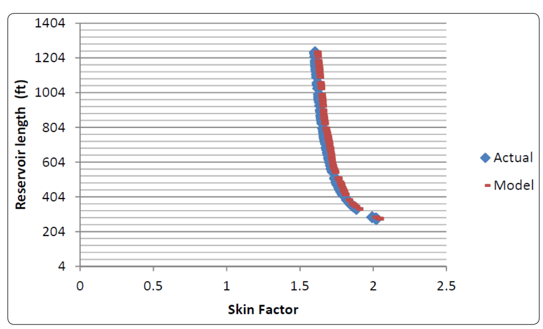

Figure 13: Trend of testing data of Reservoir length versus skin

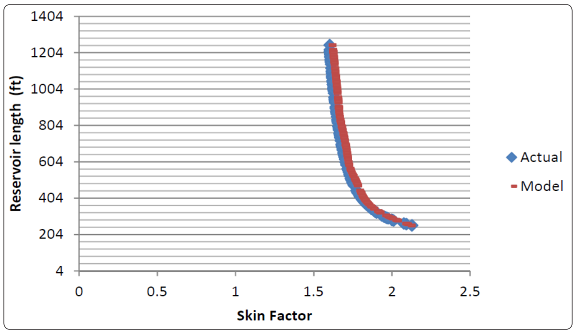

Figure 14: Trend of training data of Reservoir width versus skin

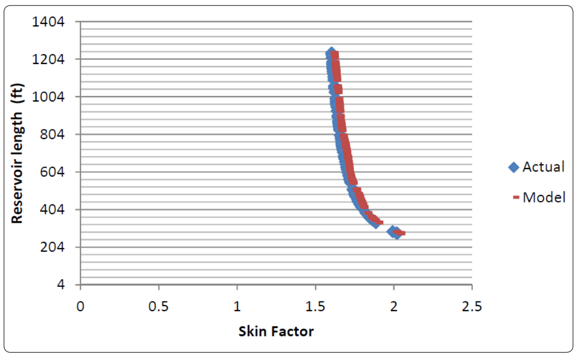

Figure 15: Trend of testing data of Reservoir width versus skin

Conclusion and Recommendation

- In this work a Fuzzy logic model was developed by using subtractive clustering radius of 0.4, due to the fact that it gives us minimum average error throughout all three cases to predict pseudo steady state shape related factor with higher accuracy. Furthermore, the parameters affecting the calculations of pseudo skin factor and data range in this project cover most of all applicable conditions in horizontal wells.
- Fuzzy logic modelling is reliable and powerful technique with regard of evaluation of complex engineering system, this due to its capability to predict and recognize the possible pattern between a set of input and output data and successfully predict and model pseudo skin shape related factor and even there is no a known mathematical relationship.
- It can be concluded from the results of trend analysis that as the well length increase the pseudo skin factor will decrease until reach the optimum value of well length and after then the pseudo skin factor will begin to increase. And since the well length is the only parameter that can be altered, this helps in determination of the optimum well length.
- Estimation are pretty accurate as compared with those values have been obtained by using Bahadori 2012 model, it has an average absolute deviation being less than 2.05%.
- The technique of fuzzy logic requires further researcher in the field of petroleum engineering, this due to the fact it has ability to provide an alternative solution to many complicated problems associated with petroleum engineering where the classic equations fail to give a satisfactory solution.
- In order to enhance the performance of fuzzy logic model and make it more reliable and precise is better to increase the numbers of input and output data Thus; more accurate results can be attained by training the model with more data points.
- More investigation in the effect of horizontal and vertical permeabilities is needed, because the pseudo skin factor depends only on flow rate and reservoir geometry and this may be attributed to the fact that the variation in vertical permeability is negligible due and the variation in horizontal permeability for homogeneous reservoir is also neglected [6-16].

Acknowledgment

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