A Permeability-Porosity-Saturation Correlation for Niger Delta

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Abstract - *Accurate estimation of rock property is essential and needed for efficient reservoir characterization. Insufficient permeability measurement makes predictions a difficult problem. Till date, it has been a difficult task to measure permeability using wire line logs sometimes it becomes capital intensive to employ other methods. In this paper, a correlation was developed which enables fast and easy determination of permeability for Niger Delta reservoir. Data were obtained from over 250 reservoirs and analyzed. About 247 data points was used for the development of the correlation. A general non-linear multiple variable regression analysis was performed on the data using DATAFIT 9.0. The statistical parameter returned shows a good match of the developed correlation and the field data. An R^2 value of 0.99 and an absolute average total percentage error of 0.009106 were obtained. A permeability cross plot was made to check the reliability of the model. Comparison with other available correlations where also made to check how closely they match the actual field data. The correlation will predict best within the range of porosity and saturation values used.*

I. INTRODUCTION

Permeability, porosity and saturation of a reservoir rock have always been considered as some of the most important parameters for formation evaluation, reservoir description and characterization.

Permeability is a measure of the ease with which a porous medium will transmit fluid. It is a function of: grain size, sorting, clay inclusions and post deposition processes. Permeability exist in three forms, Absolute, relative and effective permeability. Absolute Permeability is the measure of the ease of flow of a fluid through the reservoir rock. It is a property of rock which is independent of the type of fluid (gas, water, oil) as long as the fluid occupies 100% of the conductive (effectiveϕ) pore space. Effective permeability is the permeability of one fluid in a multi-fluid system, i.e. permeability to a fluid when its saturation is less than 100%. Relative permeability is the ratio of effective permeability to absolute permeability.

Porosity is a measure of the space in a rock not occupied by the solid structure or framework of the rock. Thus, it is a measure of how much fluid a formation can store or hold. Total or absolute porosity is the volume of pore space, i.e., the space not occupied by mineral matter, expressed as fraction or percent of bulk or over-all volume of rock, regardless of whether or not all of the pores are interconnected. The ratio of the volume of interconnected pore space to the total bulk volume of the rock is termed the effective porosity. The later is what was used in this study.

Fluid saturation is a measure of the amount of each fluid phase in the pore spaces of a rock expressed as a percentage. It is important for reserve estimation and well planning. It is mostly determined from core analysis and well logs.

II. REVIEW OF EXISTING CORRELATIONS

Empirical correlations have been developed by Morris & Beggs[1], Timur[2], and Coates and Dumanoir[3] to calculate the permeability using porosity and irreducible water saturation for sandstone reservoir.

Morris and Biggs[1] presented the following two expressions for estimating the permeability for oil and gas reservoirs:

For an oil reservoir-

$$k = 250\left(\frac{\emptyset^3}{{S_{wc}}^2}\right) \qquad 1$$

For gas reservoir-

$$k = 80\left(\frac{\emptyset^3}{S_{wc}}\right)^2 \qquad 2$$

Timur[2] proposed the following expression for estimating the permeability from connate water saturation and porosity:

$$K = \frac{0.136\ \emptyset^{4.4}}{{Sw_i}^2} \qquad 3$$

Coates-Dumanoir[4] relationship for the free-fluid model introduced a new equation that ensured zero permeability at zero porosity and when Swi = 100%. They accommodated the two conditions with the following relationship:

$$K = \left[100\emptyset_e^2\left(\frac{1-S_{wi}}{S_{wi}}\right)\right]^2 \qquad 4$$

Development of Permeability-porosity-saturation correlation

Two hundred forty-seven (247) porosity and saturation data point, gotten from different oil blocks were used for the correlation. The absolute permeability was obtained for the respective data point by the use of Coates and Denoo[3] relationship. The calculation was done with excel and the values were imported into DATAFIT 9.0 which perform the regression. The model used is of the form:

$$K = a{\emptyset_e}^b S_{wi}^c \qquad 5$$

The values of a, b and c are gotten from nonlinear iterations during the process of regression. After the regression has been done, the following correlation was developed:

$$K = 4347.2759\,\emptyset_e^{3.9392}\,S_{wi}^{-2.22195} \qquad 6$$

This can as well be written in the form of Timur2 equation as

$$K = \frac{4347.2759\,\emptyset_e^{3.9392}}{S_{wi}^{2.22195}} \qquad 7$$

R^2=0.99, an absolute average total percentage error of 0.009106%, average residual value of -31.77715 etc.

III. DISCUSSION OF RESULTS

The developed correlation was compared with other available correlations stated above. The result of the comparison is shown graphical. Due to the large number of data point involved, 11 data points were selected for the plot.

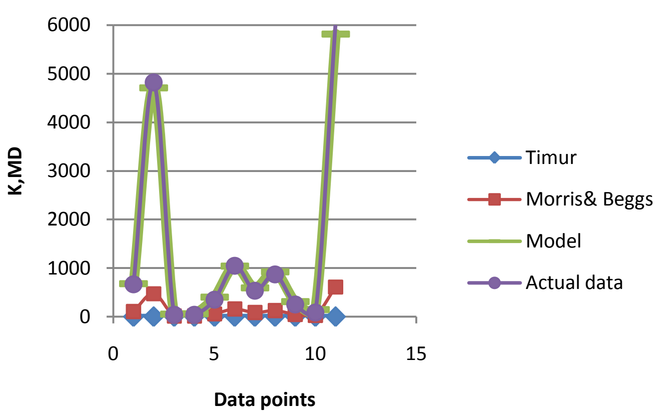

Fig 1. Comparative analysis of correlations and actual field data

Both Timur and Morris underpredicted permeability. The developed correlation matched almost perfectly with the actual field data.

Below is also a cross plot of the actual field data and the developed correlation.

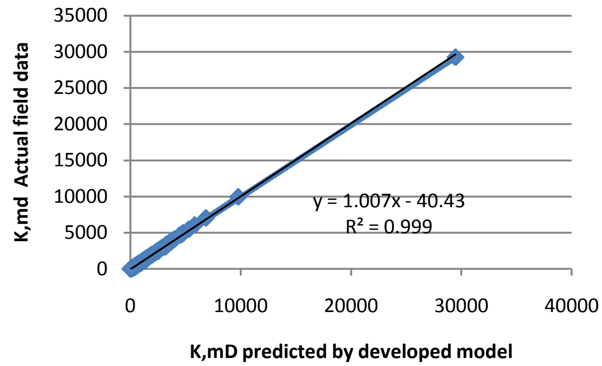

Fig 2. Permeability cross plot

Coates-Dumanoir[4] correlation gave a reasonable comparison with the developed correlation but also under predicted most of the values.

IV. CONCLUSIONS

A Permeability-porosity-saturation relationship has been established for Niger Delta. Among the correlation tested, Coates-Dumanoir[4] gave a better match. The correlation predicts best within the range of values used. The correlation can be applied to any field in Niger Delta.

REFERENCES

Coates, G.R. and Dumanoir, J.L. (1973) "A New Approach to Improved Log-Derived Permeability," SPWLA Fourteenth Annual Logging Symposium.

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Tarek Ahmed; "Reservoir Engineering Handbook."

Timur, A., "An Investigation of Permeability, Porosity, and Residual Water Saturation Relationships," *AIME*, June 1968

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Nomenclature

Swi = residual or connate water saturation

∅e = effective porosity

K = Absolute permeability

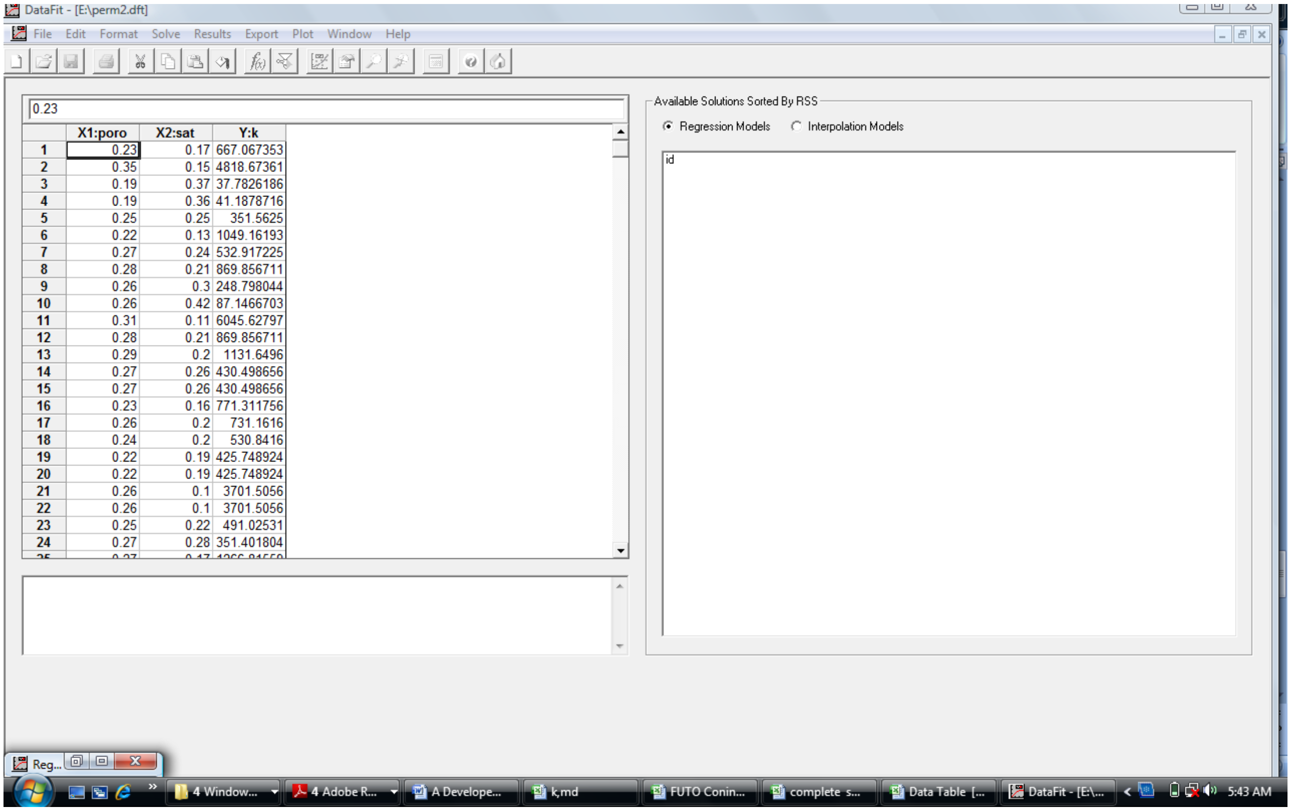


Fig 3 DATA FIT 9.0 input window for data

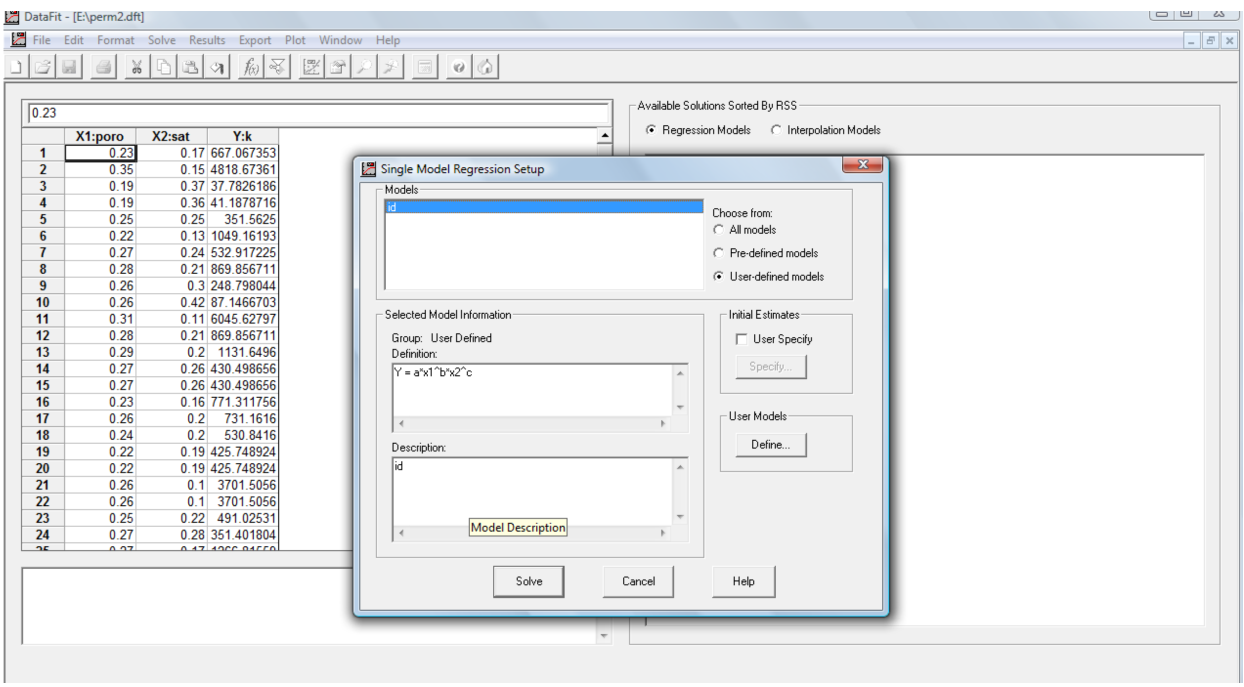
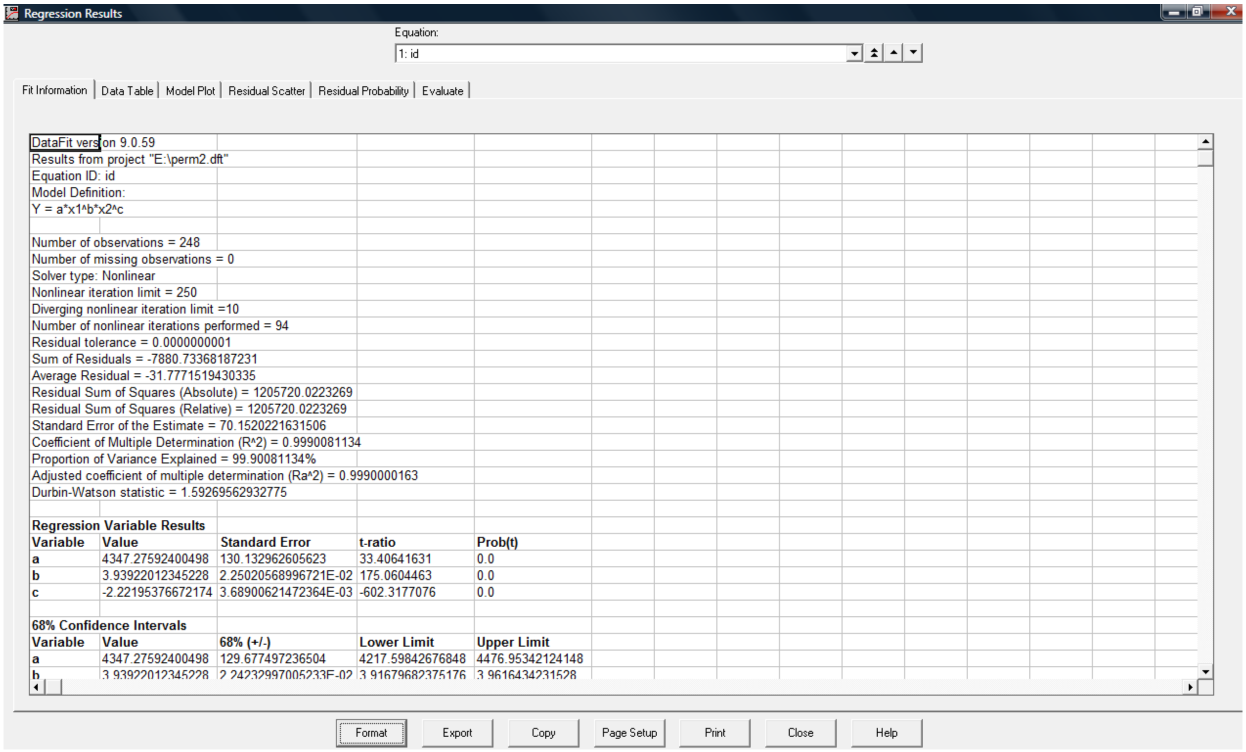


Fig 4 Regression model Input



DataFit version 9.0.59
Results from project "E:\perm2.dft"
Equation ID: id
Model Definition:
Y = a*x1^b*x2^c

Number of observations = 248
Number of missing observations = 0
Solver type: Nonlinear
Nonlinear iteration limit = 250
Diverging nonlinear iteration limit =10
Number of nonlinear iterations performed = 94
Residual tolerance = 0.0000000001
Sum of Residuals = -7880.73368187231
Average Residual = -31.7771519430335
Residual Sum of Squares (Absolute) = 1205720.0223269
Residual Sum of Squares (Relative) = 1205720.0223269
Standard Error of the Estimate = 70.1520221631506
Coefficient of Multiple Determination (R^2) = 0.9990081134
Proportion of Variance Explained = 99.90081134%
Adjusted coefficient of multiple determination (Ra^2) = 0.9990000163
Durbin-Watson statistic = 1.59269562932775

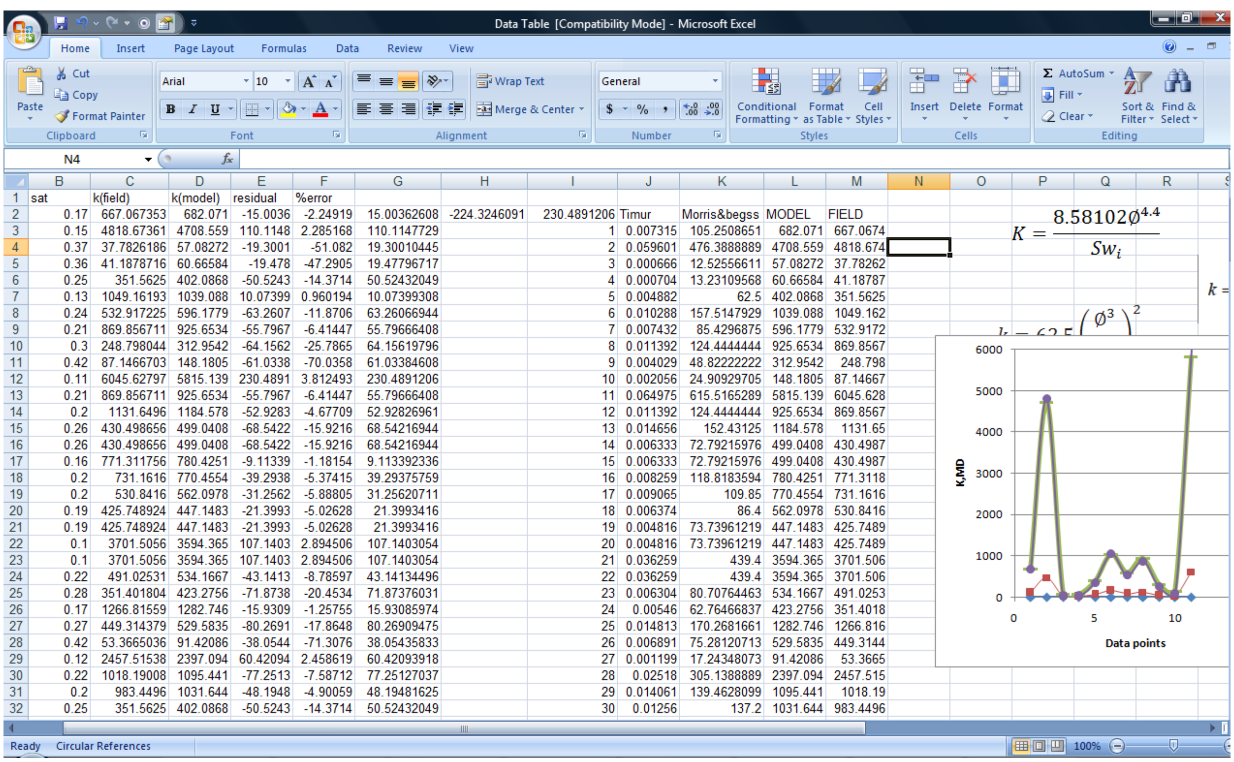
Regression Variable Results

Variable	Value	Standard Error	t-ratio	Prob(t)
a	4347.27592400498	130.132962605623	33.40641631	0.0
b	3.93922012345228	2.25020568996721E-02	175.0604463	0.0
c	-2.22195376672174	3.68900621472364E-03	-602.3177076	0.0

68% Confidence Intervals

Variable	Value	68% (+/-)	Lower Limit	Upper Limit
a	4347.27592400498	129.677497236504	4217.59842676848	4476.95342124148
b	3.93922012345228	2.24232997005233E-02	3.91679682375176	3.9616434231528

Fig 5 DATAFIT 9.0 result interface



	B	C	D	E	F	G	H	I	J	K	L	M
1	sat	k(field)	k(model)	residual	%error							
2	0.17	667.067353	682.071	-15.0036	-2.24919	15.00362608	-224.3246091	230.4891206	Timur	Morris&begss	MODEL	FIELD
3	0.15	4818.67361	4708.559	110.1148	2.285168	110.1147729		1	0.007315	105.2508651	682.071	667.0674
4	0.37	37.7826186	57.08272	-19.3001	-51.082	19.30010445		2	0.059601	476.3888889	4708.559	4818.674
5	0.36	41.1878716	60.66584	-19.478	-47.2905	19.47796717		3	0.000666	12.52556611	57.08272	37.78262
6	0.25	351.5625	402.0868	-50.5243	-14.3714	50.52432049		4	0.000704	13.23109568	60.66584	41.18787
7	0.13	1049.16193	1039.088	10.07399	0.960194	10.07399308		5	0.004882	62.5	402.0868	351.5625
8	0.24	532.917225	596.1779	-63.2607	-11.8706	63.26066944		6	0.010288	157.5147929	1039.088	1049.162
9	0.21	869.856711	925.6534	-55.7967	-6.41447	55.79666408		7	0.007432	85.4296875	596.1779	532.9172
10	0.3	248.798044	312.9542	-64.1562	-25.7865	64.15619796		8	0.011392	124.4444444	925.6534	869.8567
11	0.42	87.1466703	148.1805	-61.0338	-70.0358	61.03384608		9	0.004029	48.82222222	312.9542	248.798
12	0.11	6045.62797	5815.139	230.4891	3.812493	230.4891206		10	0.002056	24.90929705	148.1805	87.14667
13	0.21	869.856711	925.6534	-55.7967	-6.41447	55.79666408		11	0.064975	615.5165289	5815.139	6045.628
14	0.2	1131.6496	1184.578	-52.9283	-4.67709	52.92826961		12	0.011392	124.4444444	925.6534	869.8567
15	0.26	430.498656	499.0408	-68.5422	-15.9216	68.54216944		13	0.014656	152.43125	1184.578	1131.65
16	0.26	430.498656	499.0408	-68.5422	-15.9216	68.54216944		14	0.006333	72.79215976	499.0408	430.4987
17	0.16	771.311756	780.4251	-9.11339	-1.18154	9.113392336		15	0.006333	72.79215976	499.0408	430.4987
18	0.2	731.1616	770.4554	-39.2938	-5.37415	39.29375759		16	0.008259	118.8183594	780.4251	771.3118
19	0.2	530.8416	562.0978	-31.2562	-5.88805	31.25620711		17	0.009065	109.85	770.4554	731.1616
20	0.19	425.748924	447.1483	-21.3993	-5.02628	21.3993416		18	0.006374	86.4	562.0978	530.8416
21	0.19	425.748924	447.1483	-21.3993	-5.02628	21.3993416		19	0.004816	73.73961219	447.1483	425.7489
22	0.1	3701.5056	3594.365	107.1403	2.894506	107.1403054		20	0.004816	73.73961219	447.1483	425.7489
23	0.1	3701.5056	3594.365	107.1403	2.894506	107.1403054		21	0.036259	439.4	3594.365	3701.506
24	0.22	491.02531	534.1667	-43.1413	-8.78597	43.14134496		22	0.036259	439.4	3594.365	3701.506
25	0.28	351.401804	423.2756	-71.8738	-20.4534	71.87376031		23	0.006304	80.70764463	534.1667	491.0253
26	0.17	1266.81559	1282.746	-15.9309	-1.25755	15.93085974		24	0.00546	62.76466837	423.2756	351.4018
27	0.27	449.314379	529.5835	-80.2691	-17.8648	80.26909475		25	0.014813	170.2681661	1282.746	1266.816
28	0.42	53.3665036	91.42086	-38.0544	-71.3076	38.05435833		26	0.006891	75.28120713	529.5835	449.3144
29	0.12	2457.51538	2397.094	60.42094	2.458619	60.42093918		27	0.001199	17.24348073	91.42086	53.3665
30	0.22	1018.19008	1095.441	-77.2513	-7.58712	77.25127037		28	0.02518	305.1388889	2397.094	2457.515
31	0.2	983.4496	1031.644	-48.1948	-4.90059	48.19481625		29	0.014061	139.4628099	1095.441	1018.19
32	0.25	351.5625	402.0868	-50.5243	-14.3714	50.52432049		30	0.01256	137.2	1031.644	983.4496

Fig 6.0 Excel evaluations