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APPENDICES

APPENDIX A Published Correlations Used in This Study

Table A1 Published P_b correlations used in this work

Author	Correlation
Standing (1947)	$P_b = 18.2\left[\left(\frac{R_s}{\gamma_g}\right)^{0.88} \cdot (10)^{0.00091T-0.0125API} - 1.4\right]$
Calhoun (1976)	$P_b = 204.257K[(R_s)^{0.51} - 4.7927]$ $K = \exp[0.00077T - 0.0097API - 0.4003\gamma_g]$
Glaso (1980)	$\log P_b = 1.7669 + 1.7447 \log A - (\log A)^2$ $A = \left[\frac{R_s}{\gamma_g}\right]^{0.816} \cdot \frac{T^{0.172}}{API^{0.989}}$
Vazquez and Beggs (1980)	$P_b = \left[(c_1 R_s/\gamma_g)e^{\frac{-c_3 API}{T}}\right]^{c_2}$ $API \leq 30;$ $c_1 = 27.624, c_2 = 0.914328, c_3 = 11.172$ $API > 30;$ $c_2 = 56.180, c_2 = 0.842460, c_3 = 10.393$
Al-Marhoun (1988)	$P_b = 0.00538088R_s^{0.715082}\gamma_g^{-1.87784}\gamma_o^{3.1437}T^{1.32657}$
Petrosky Jr. and Farshad (1993)	$P_b = \left[\frac{112.727R_s^{0.577421}}{\gamma_g^{0.8439}10^X}\right] - 1391.051$ $X = 0.0007916API^{1.541} - 0.000004561T^{1.3911}$
Dokla and Osman (1991)	$P_b = 8.36386 \times 10^{-5}\left(\frac{\gamma_o^{0.107991}R_s^{0.724047}}{\gamma_g^{1.01049}(T+460)^{0.952584}}\right)$

Kartoatmodjo and Schmidt (1991)	$P_b = \left(\frac{R_s}{c_1 \gamma_g^{c_2} 10^{c_3 API/(T+460)}}\right)^{c_4}$ $API \leq 30;$ $c_1 = 0.05958, c_2 = 0.7972, c_3 = 13.1405, c_4 = 0.9986$ $API > 30;$ $c_1 = 0.03150, c_2 = 0.7587, c_3 = 11.2895, c_4 = 0.9143$
De Ghetto and Villa (1994)	$10 < API \leq 22.3;$ $P_b = 15.7286\left[\left(\frac{R_s}{\gamma_g}\right)^{0.7885} \cdot 10^{(0.002T-0.142API)}\right]$ $22.3 < API \leq 31.1;$ $P_b = \left(\frac{R_s}{0.09902(\gamma_g)^{0.2181} 10^{7.2153API/T}}\right)^{0.9997}$ $31.1 < API;$ $P_b = 31.7648\left[\left(\frac{R_s}{\gamma_g}\right)^{0.7857} \cdot 10^{(0.0009T-0.0148API)}\right]$
Frashad et al. (1996)	$P_b = 64.14\left[R_s^{0.6343}\gamma_g^{-1.15036}10^{(0.000335T-0.0101API)} - 7.2818\right]$
Almehaideb (1997)	$P_b = -620.592 + 6.23087\frac{R_s\gamma_o}{\gamma_g B_o^{1.38559}} + 2.89868\text{T}$
Velarde et al. (1997)	$P_b = 1091.47\left[R_s^{0.081465}\gamma_g^{-0.161488}10^X - 0.740152\right]^{5.354891}$ $X = 0.013098T^{0.282372} - 8.2 \cdot 10^{-6}API^{2.176124}$
Hanafy et al. (1997)	$P_b = 204.257K[R_s^{0.51} - 4.7927]$ $K = e^{[0.00077T-0.0097API-0.4003\gamma_g]}$
Al-Shammasi (1999)	$P_b = \gamma_o^{5.527215}e^{-1.841408(\gamma_o\gamma_g)}\left[R_s\gamma_g(T+460)\right]^{0.783716}$

Valkó and Mccain Jr (2003)	$\ln P_b = 7.475 + 0.713Z + 0.0075Z^2$ $Z = \sum_{n=1}^{4} Z_n = c_{0_n} + c_{1_n}X_n + c_{2_n}X_n^2 + c_{3_n}X_n^3$ <table><tr><td>n</td><td>X</td><td>c_0</td><td>c_1</td><td>c_2</td><td>c_3</td></tr><tr><td>1</td><td>$\ln R_s$</td><td>-5.48</td><td>-0.0378</td><td>0.281</td><td>-0.0206</td></tr><tr><td>2</td><td>API</td><td>1.27</td><td>-0.0449</td><td>4.36×10^{-4}</td><td>-4.76×10^{-6}</td></tr><tr><td>3</td><td>γ_g</td><td>4.51</td><td>-10.84</td><td>8.39</td><td>-2.34</td></tr><tr><td>4</td><td>T_{res}</td><td>-0.7835</td><td>6.23×10^{-3}</td><td>-1.22×10^{-5}</td><td>1.03×10^{-8}</td></tr></table>
Dindoruk and Christman (2004)	$P_b = c_8\left(\frac{R_s^{c_9}}{\gamma_g c_{10}} 10^A + c_{11}\right)$ $A = \frac{c_1 T^{c_2} + c_3 API^{c_4}}{\left(c_5 + \frac{2R_s^{c_6}}{\gamma_g^{c_7}}\right)^2}$ $c_1 = 0.142828 \times 10^{-10}, c_2 = 2.844591797$ $c_3 = -6.74896 \times 10^{-4}, c_4 = 1.225226436$ $c_5 = 0.033383304, c_6 = -0.272945957$ $c_7 = -0.084226069, c_8 = 1.869979257$ $c_9 = 1.221486524, c_{10} = 1.370508349, c_{11} = 0.011688308$
Nikpoor and Khanamiri (2011)	$\log\left(\frac{P_b}{14.7}\right) = -2.4255\left(\frac{460}{T + 460}\right)$ $- 4.2029 \log \gamma_g + 0.8732 \log R_s$ $- 1.1596\left(\frac{(T + 460)\gamma_g}{460\gamma_o}\right) + 3.3058\gamma_o$

Table A2 Published B_{ob} correlations used in this work

Method	Equation
Standing (1947)	$B_{ob} = 0.972 + 1.472 \times 10^{-4}\left[R_s\left(\frac{\gamma_g}{API}\right)^{0.5} + 1.25T\right]^{1.175}$
Glaso (1980)	$\log(B_{ob} - 1) = -6.58511 + 2.91329\log A - 0.27683(\log A)^2$ $A = R_s\left(\frac{\gamma_g}{\gamma_o}\right)^{0.526} + 0.968T$
Al-Marhoun (1988)	$B_{ob} = 0.497069 + 0.862963 \times 10^{-3}T + 0.182594 \times 10^{-2}A + 0.318099 \times 10^{-5}A^2$ $A = R_s^{0.74239}\gamma_g^{0.323294}\gamma_o^{-1.20247}$
Al-Marhoun (1992)	$B_{ob} = 1 + c_1R_s + c_2R_s(\gamma_g/\gamma_o) + c_3R_s(1-\gamma_o)(T-60) + c_4(T-60)$ $c_1 = 1.77342 \times 10^{-4}, c_2 = 2.20163 \times 10^{-4}$ $c_3 = 4.292580 \times 10^{-6} c_4 = 5.28707 \times 10^{-4}$
Omar and Todd (1993)	$B_{ob} = 0.972 + 1.47 \times 10^{-4}\left[R_s\left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25T_{res}\right]^{X}$ $X = 1.1663 + 7.062 \times 10^{-3}(API/\gamma_g) - 0.0399\gamma_g$
Petrosky Jr. and Farshad (1993)	$B_{ob} = 1.0113 + 7.204 \times 10^{-5}\left[\frac{R_s^{0.3738}\gamma_g^{0.2914}}{\gamma_o^{0.6265}} + 0.2464T^{0.5371}\right]^{3.0906}$
Almehaideb (1997)	$B_{ob} = 1.122018 + 1.410 \times 10^{-6}\left(\frac{R_sT}{\gamma_o^2}\right)$
Hanafy et al. (1997)	$B_{ob} = (1.0031 + 0.0008T)exp[0.0004R_s + 0.0006\,\gamma_o/\gamma_g]$
Al-Shammasi (1999)	$B_{ob} = 1 + \frac{0.000412R_s}{\gamma_o} + \frac{0.00065(\mathrm{T}-60)}{\gamma_o}$

Hemmati and Kharrat (2007)	$B_{ob} = 1 + 10^X$ $X = -4.6862 + 1.5959\log A - 0.0566(\log A)^2$ $A = R_s\left(\frac{\gamma_g}{\gamma_o}\right)^{0.5946} + 1.7439T$
Nikpoor and Khanamiri (2011)	$B_{ob} = 1 + 0.13142\frac{T}{150} - 0.05408\gamma_o - 0.02865\gamma_g +$ $0.07352\left(\frac{R_s\gamma_o}{700\gamma_g}\right) + 0.24091\left(\frac{R_s\gamma_g}{700\gamma_o}\right)$

Table A3 Published R_s correlations used in this work

Method	Equation
Standing (1947)	$R_s = \gamma_g\left[\left(\frac{P}{18.2} + 1.4\right)10^{(0.0125API - 0.00091T)}\right]^{1.2048}$
Glaso (1980)	$R_s = \gamma_g\left[\frac{API^{0.989}X}{T^{0.172}}\right]^{1.2255}$ $X = 10^{\left(2.8869 - \sqrt{14.1811 - 3.3093\log P}\right)}$
Al-Marhoun (1988)	$R_s = \left[\frac{P_b\gamma_g^{1.87784}}{0.00538088\gamma_o^{3.1437}}\right]$
Petrosky Jr. and Farshad (1993)	$R_s = \left[\left(\frac{P_b}{112.727} + 12.34\right)\gamma_g^{0.8439}10^X\right]^{1.73184}$ $X = 0.00079116API^{1.541} - 0.0004561T^{1.3911}$
Hemmati and Kharrat (2007)	$R_s = \left[0.1769\gamma_g^{1.0674}\gamma_o^{-5.0956}T^{-0.1294}P_b\right]^{1.0857}$

Table A4 Published μ_o correlations used in this work

Method	Equation
Beal (1946)	$\mu_o = 0.001(P - P_b)\cdot\left(0.024\mu_{ob}^{1.6} + 0.038\mu_{ob}^{0.56}\right) + \mu_{ob}$
Vazquez and Beggs (1980)	$\mu_o = \mu_{ob}\left(\frac{P}{P_b}\right)^X$ $X = 2.6282P^{1.187} \times e^{[-11.513-(8.98\times10^{-5})P]}$
Khan (1987)	$\mu_o = \mu_{ob}\cdot e^{[9.6\times10^{-5}(P-P_b)]}$
Kartoatmodjo and Schmidt (1991)	$\mu_o = 1.0081\mu_{ob} + 0.001127(P - P_b)$ $\times\left(-0.006517\mu_{ob}^{1.8148} + 0.038\mu_{ob}^{1.59}\right)$
Petrosky and Farshad (1995)	$\mu_o = \mu_{ob} + 0.0013449(P - P_b) \times 10^X$ $X = -1.0146 + 1.3322\log\mu_{ob} - 0.4876(\log\mu_{ob})^2$ $- 1.15036(\log\mu_{ob})^3$
Isehunwa et al. (2006)	$\mu_o = \mu_{ob}\cdot e^{1.02\times10^{-4}(P-P_b)}$
Abedini et al. (2010)	$\mu_o = \mu_{ob} + 0.001(P - P_b)\left(a_1\mu_{ob}^{b_1} + a_2\mu_{ob}^{b_2} + a_3\mu_{ob}^{b_3}\right.$ $\left.+ a_4P_b^{b_4} + a_5P_b^{b_5} + a_6P_b^{b_6} + a_7P_b^{b_7}\right)$ $a_1 = 0.05601, a_2 = 0.47557, a_3 = -0.2257,$ $a_4 = -0.29598, a_5 = -0.7734, a_6 = -0.42436,$ $a_7 = -1.64149$ $b_1 = 1.45198, b_2 = 0.35997, b_3 = 0.86389,$ $b_4 = -0.41866, b_5 = -0.29981, b_6 = -0.1946,$ $b_7 = -0.31339$

Appendix B Testing Results

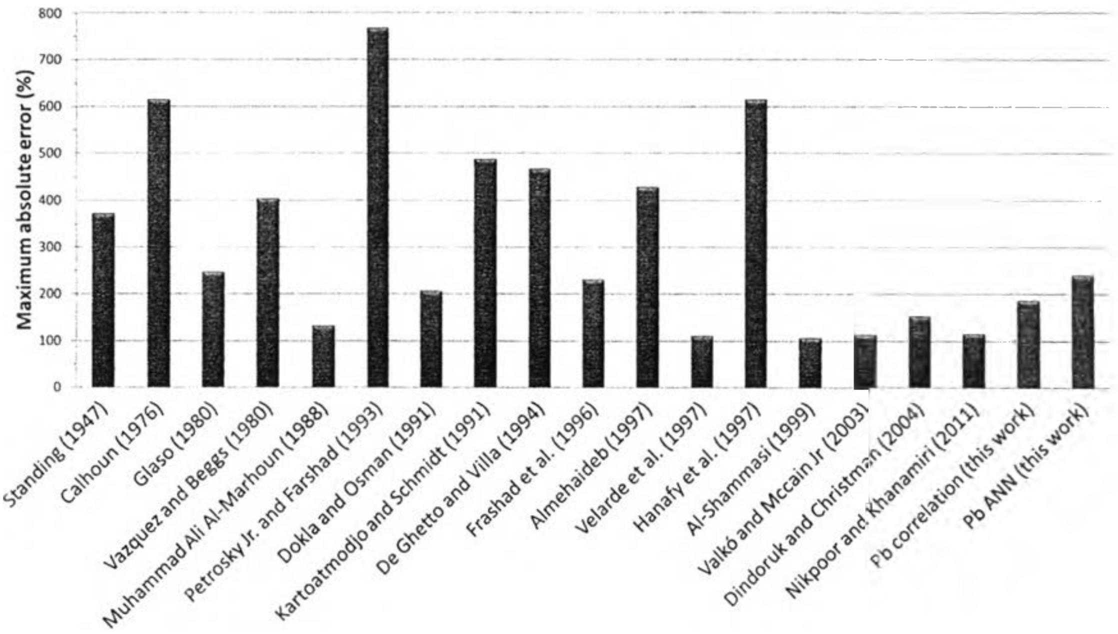

Figure B1 Maximum absolute error plots for the P_b testing results.

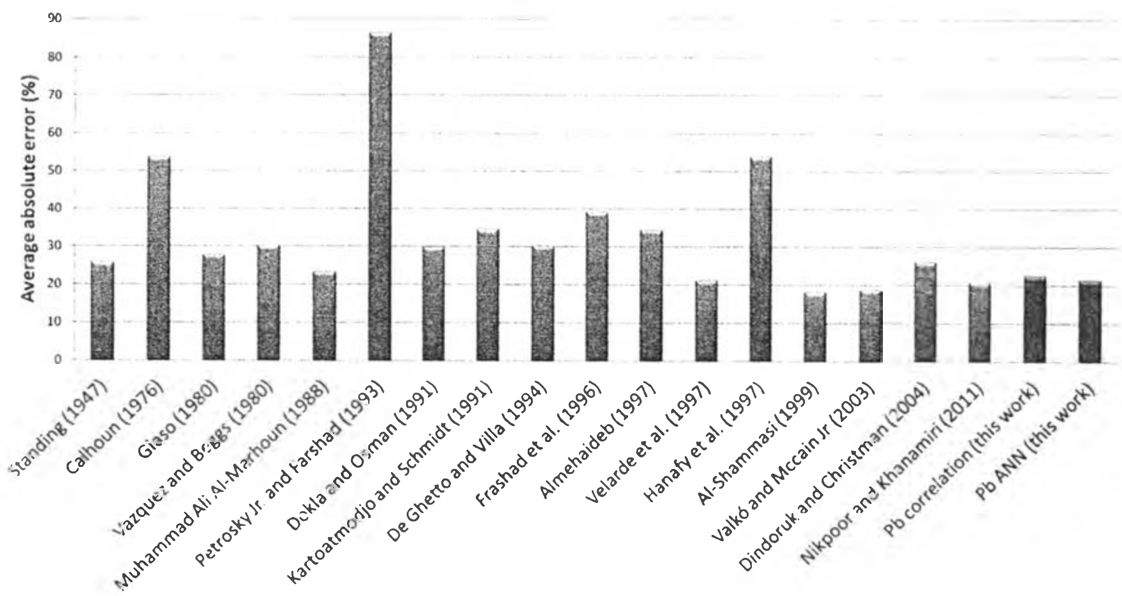

Figure B2 Average absolute error plots for the P_b testing results.

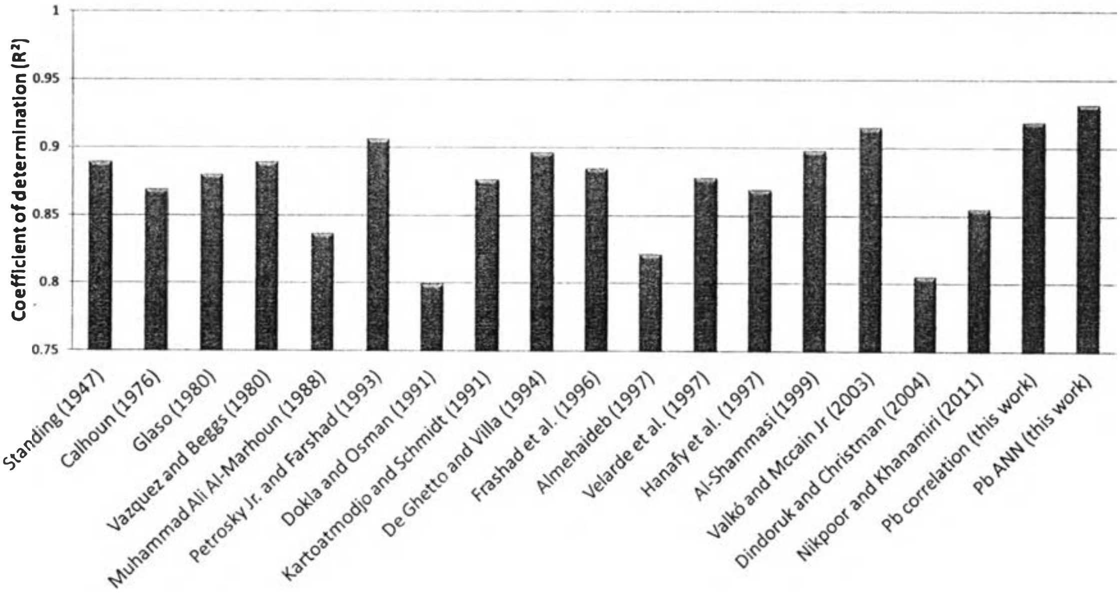

Figure B3 Coefficient of determination plots for the P_b testing results.

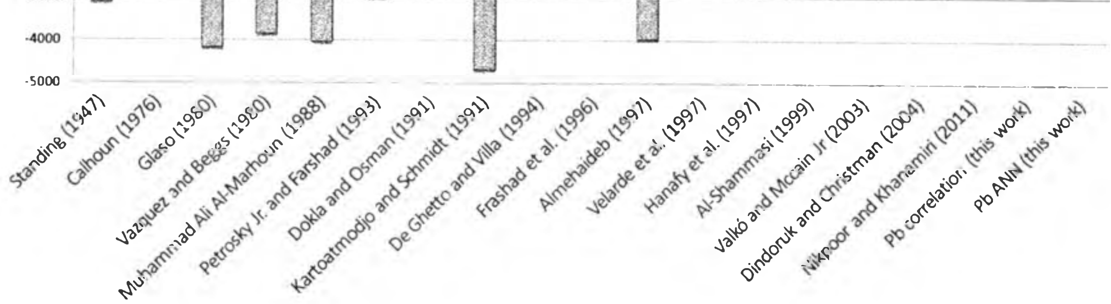

Figure B4 Range of error plots for the P_b testing results.

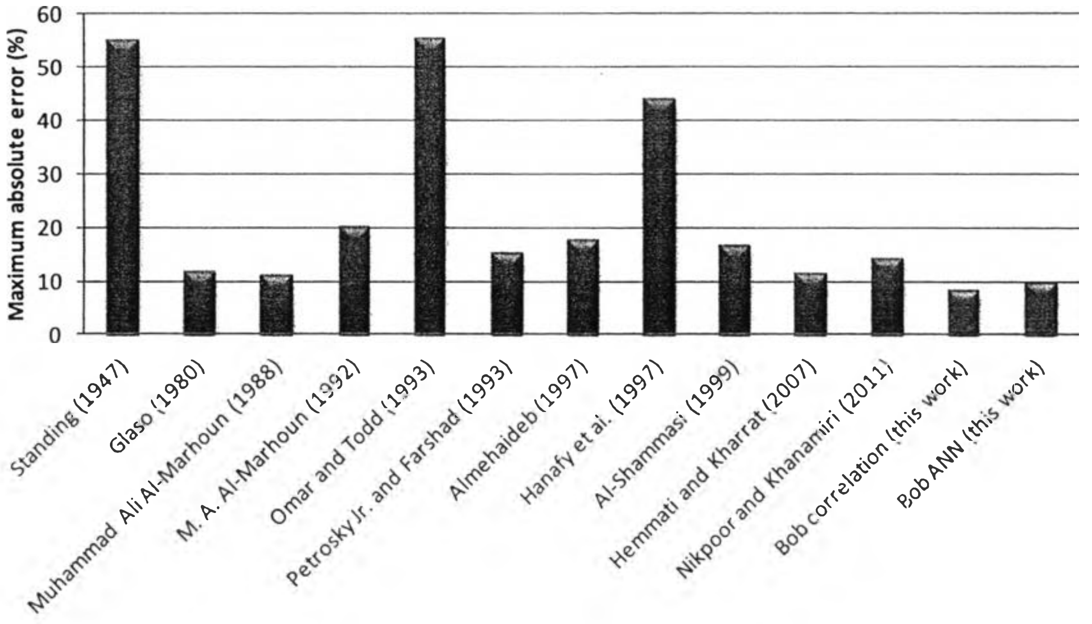

Figure B5 Maximum absolute error plots for the B_{ob} testing results.

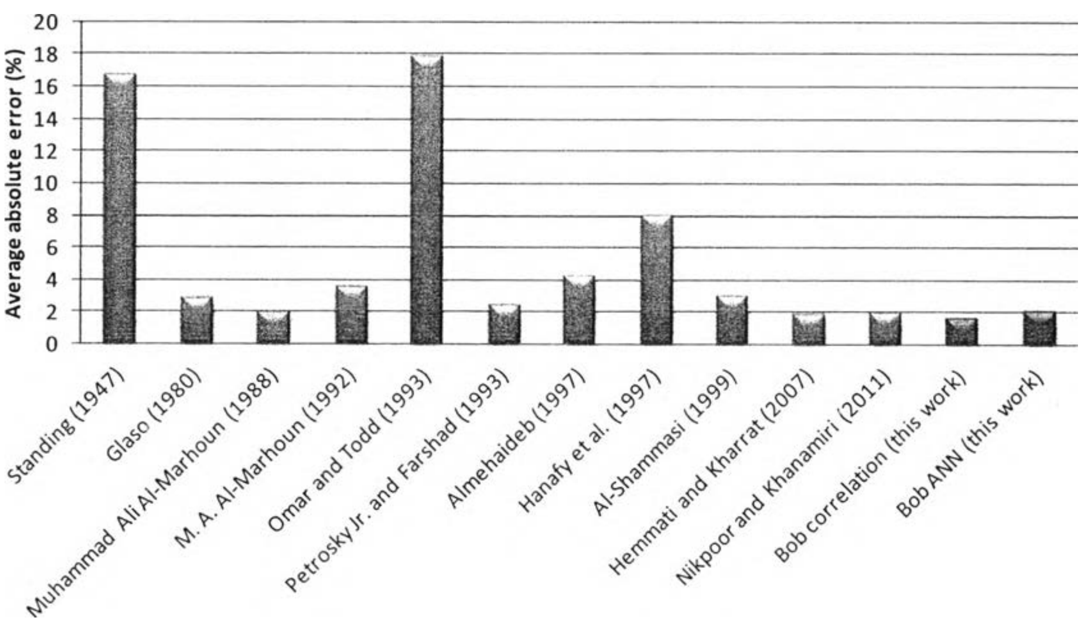

Figure B6 Average absolute error plots for the B_{ob} testing results.

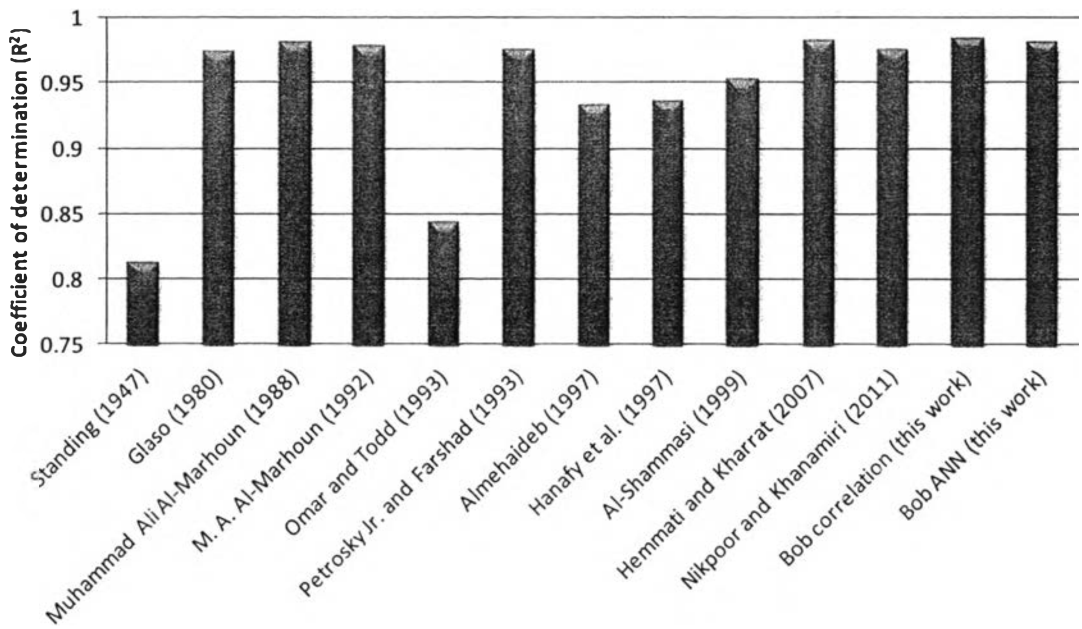

Figure B7 Coefficient of determination plots for the B_{ob} testing results.

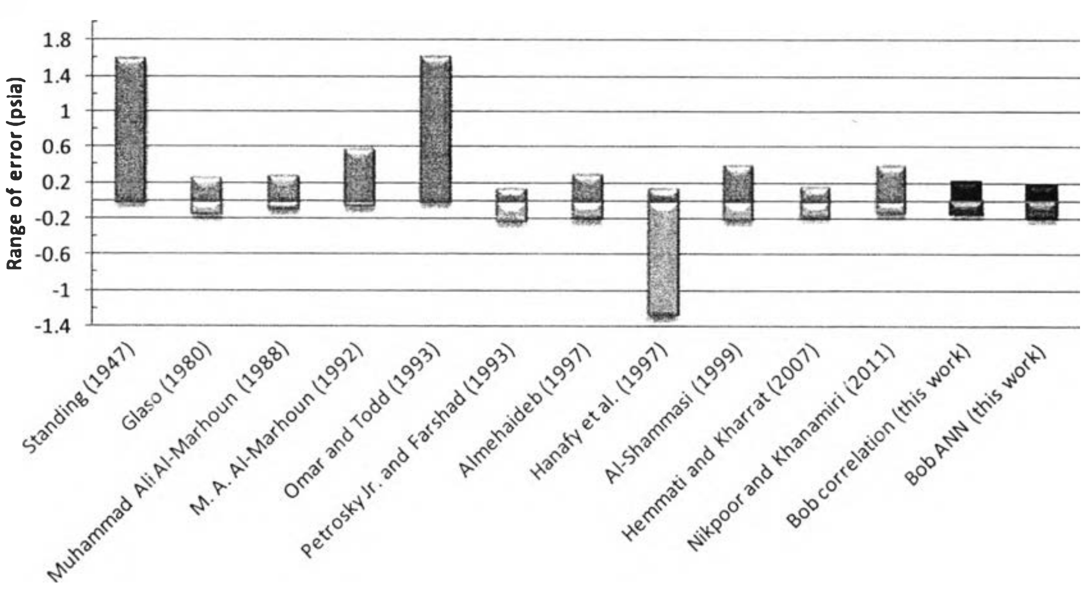

Figure B8 Range of error plots for the B_{ob} testing results.

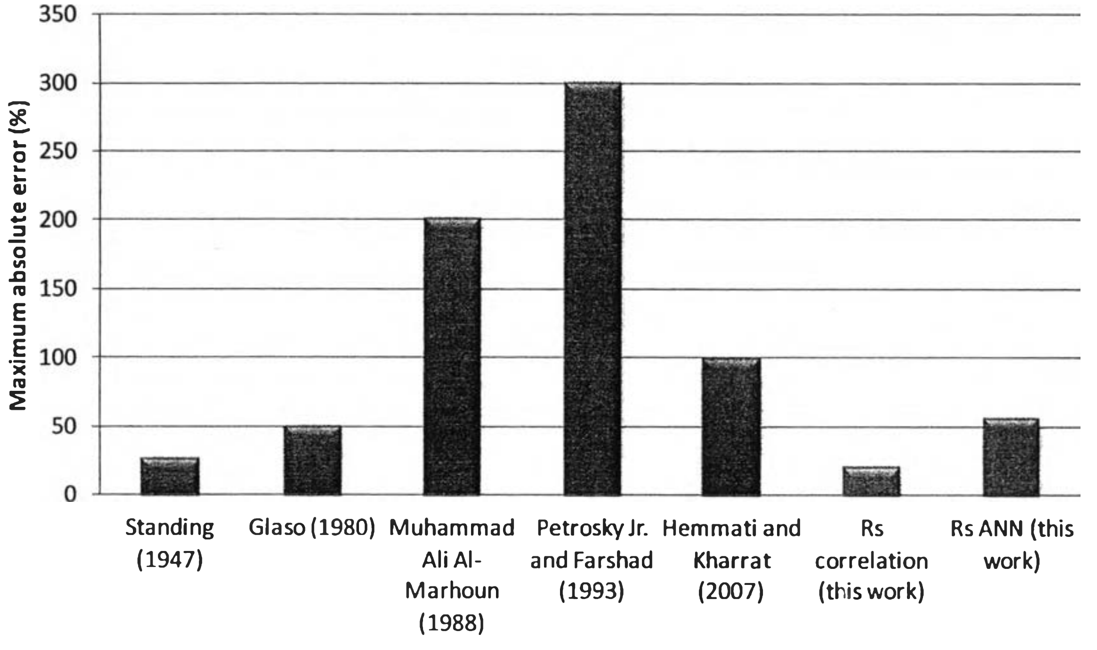

Figure B9 Maximum absolute error plots for the R_s testing results.

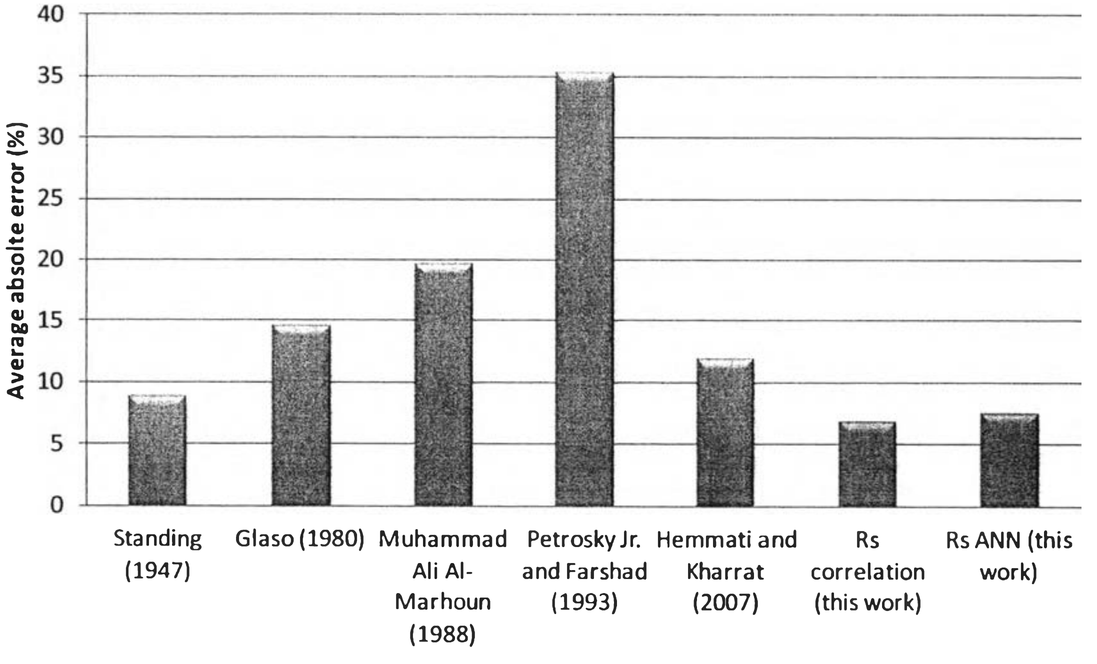

Figure B10 Average absolute error plots for the R_s testing results.

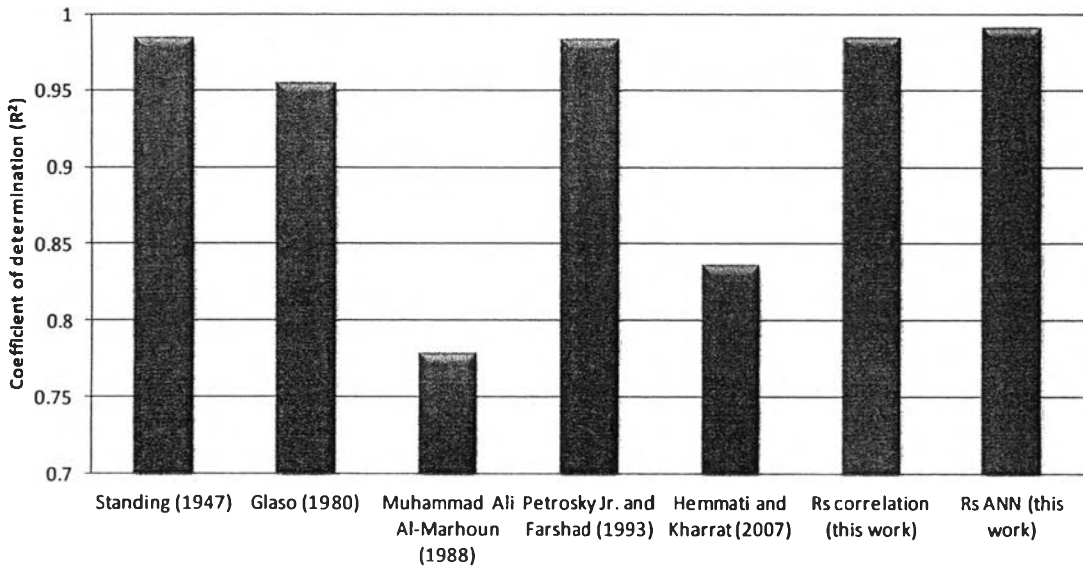

Figure B11 Coefficient of Determination plots for the R_s testing results.

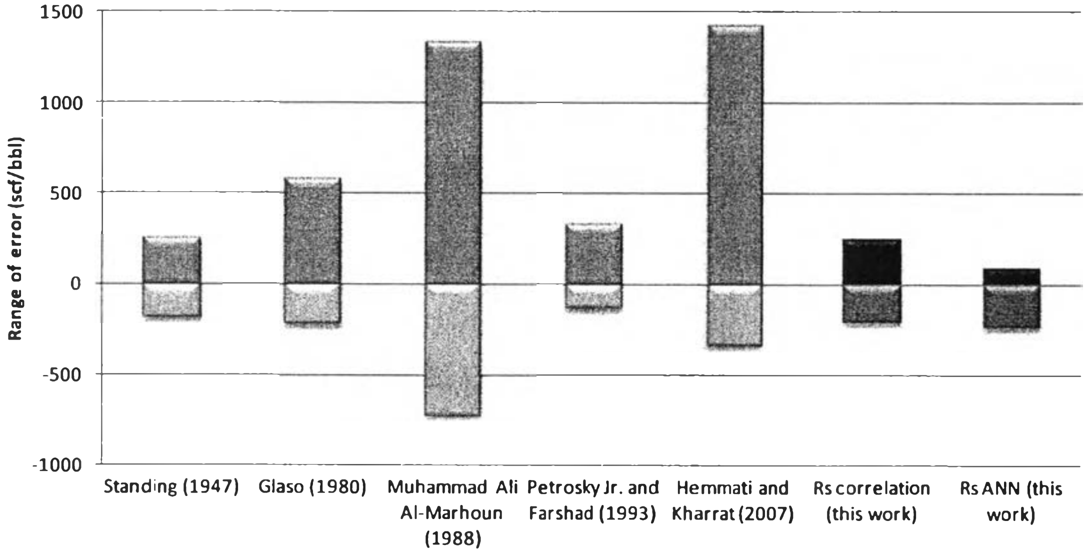

Figure B12 Range of error plots for the R_s testing results.

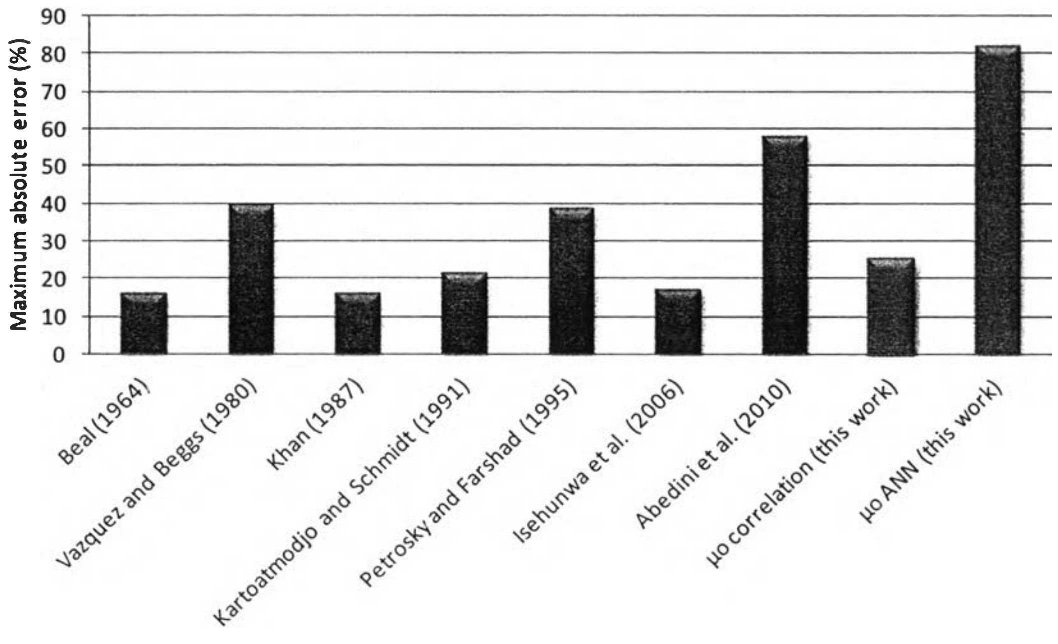

Figure B13 Maximum absolute error plots for the μ_o testing results.

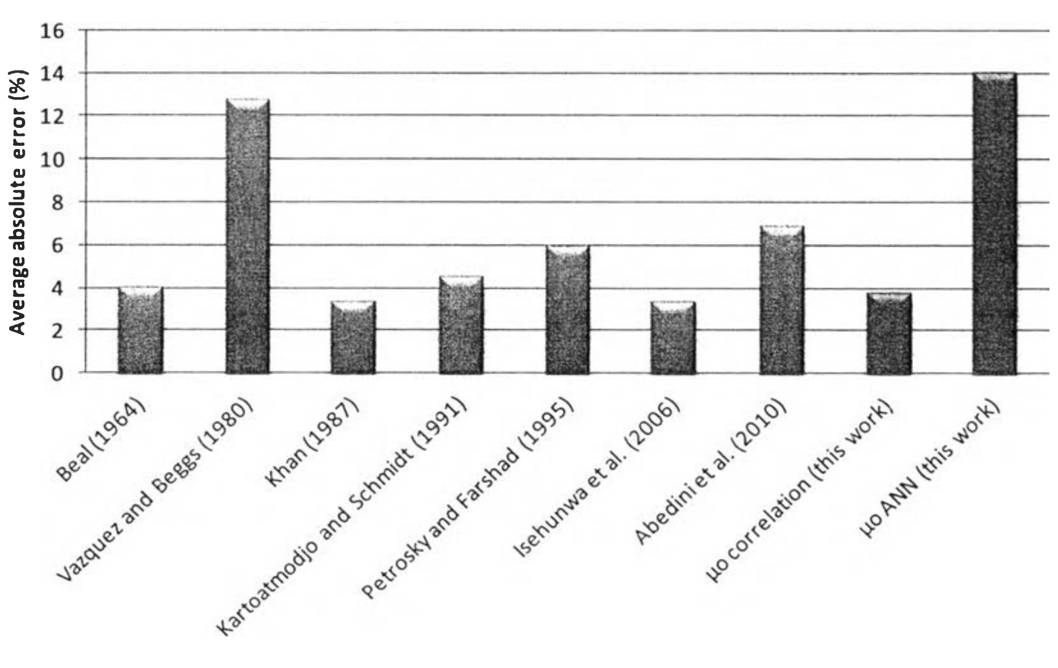

Figure B14 Average absolute error plots for the μ_o testing results.

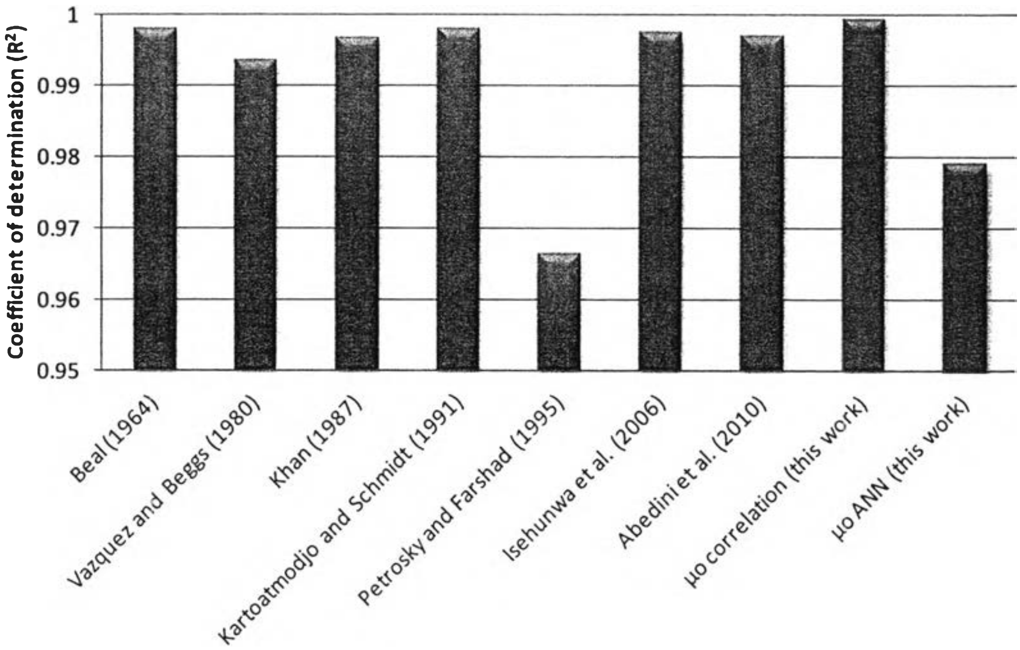

Figure B15 Coefficient of determination plots for the μ_o testing results.

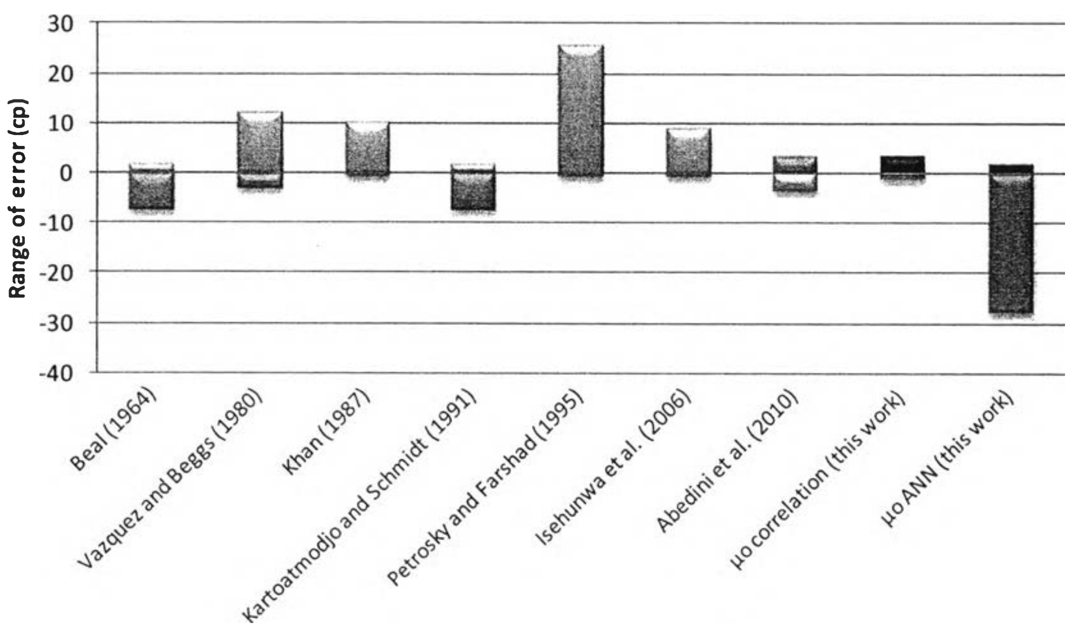

Figure B16 Range of error plots for the μ_o testing results.

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Proceedings:

1. Cuptasanti, W.; Torabi, F.; and Saiwan, C. (2013, April 23) Modeling of Crude Oil Properties Using Artificial Neural Network (ANN). Proceedings of the 4th Research Symposium on Petrochemicals and Materials Technology and The 19th PPC Symposium on Petroleum, Petrochemicals, and Polymers. Bangkok, Thailand.
2. Cuptasanti, W.; Torabi, F.; and Saiwan, C. (2013, September 29-October 2) Modeling of Crude Oil Properties Using Artificial Neural Network (ANN). The 16th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, Rhodes Island, Greece.