Reservoir Technologies

Restec

Black oils Correlations

Comparative Study

Dr. Muhammad Al-Marhoun,
Managing Director

Saturday, 26 April, 2014

Black oils Correlations

- Introduction to correlations
- Types of correlations
- Evaluation of empirically derived PVT properties for Middle East crude oils

Introduction to correlations

- PVT properties are obtained from laboratory experiment using oil representative samples
- However, values of reservoir liquid and gas properties are often needed when laboratory detailed PVT data are not available
- Therefore, correlations are used to estimate those properties
- Correlation are based on easily obtained data like R_s, γ_g, P, T, API

Introduction to correlations

- PVT properties depend on pressure, temperature and chemical compositions
- For the development of a correlation, geological condition is considered important because the chemical composition of crude oil differs from region to region
- To account for regional characteristics, PVT correlations need to be modified for their application by recalculating the correlation constants for the region of interest

Why we need correlations?

They are useful

- in making estimates for experimental design
- as a check against laboratory results
- In estimating properties when sampling is impossible or uneconomical
- In generalization of properties

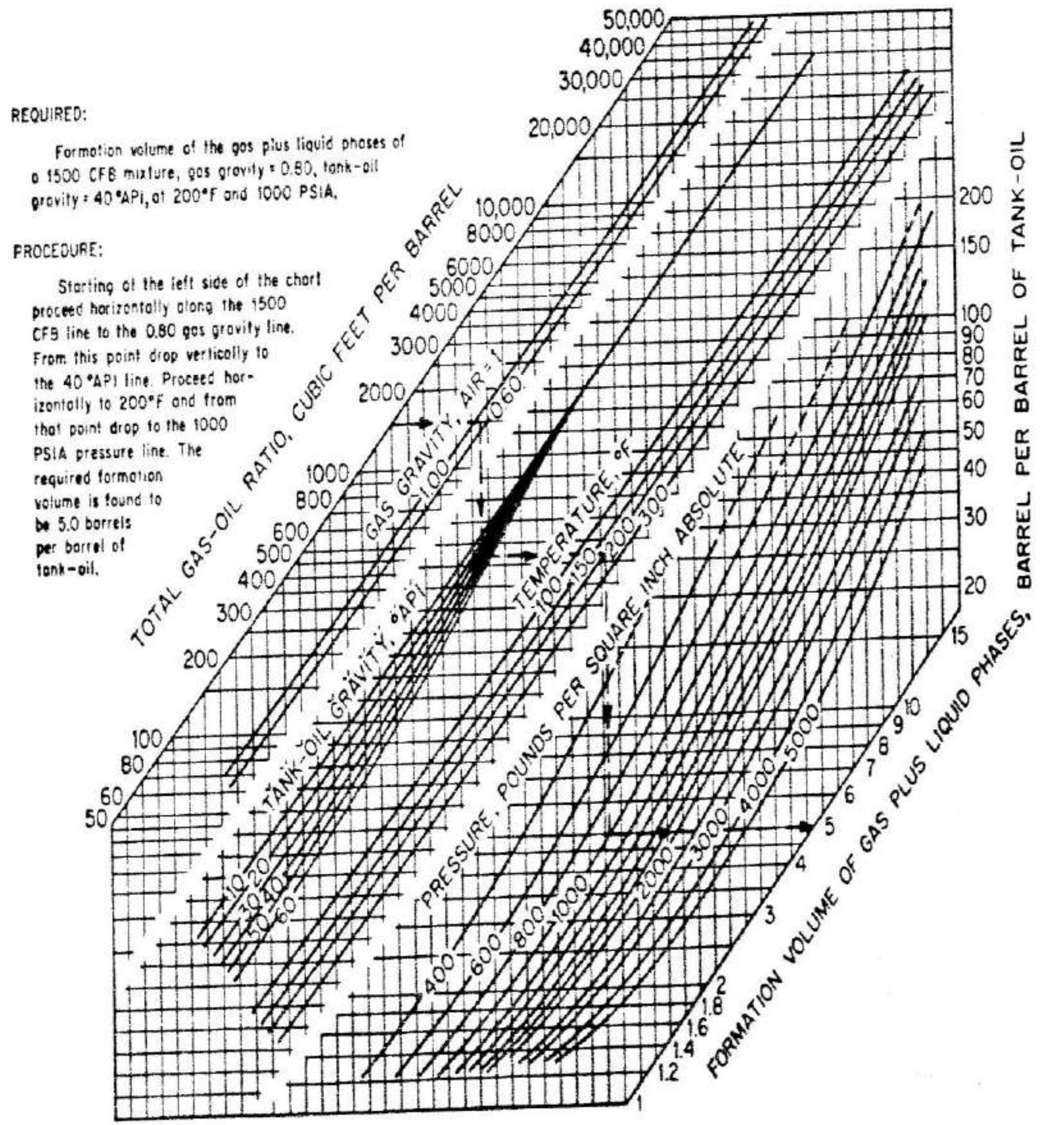
  - it is impossible to run experiments on all possible reservoir or surface conditions

Types of correlations

- Graphs
- Nomographs
- Equations

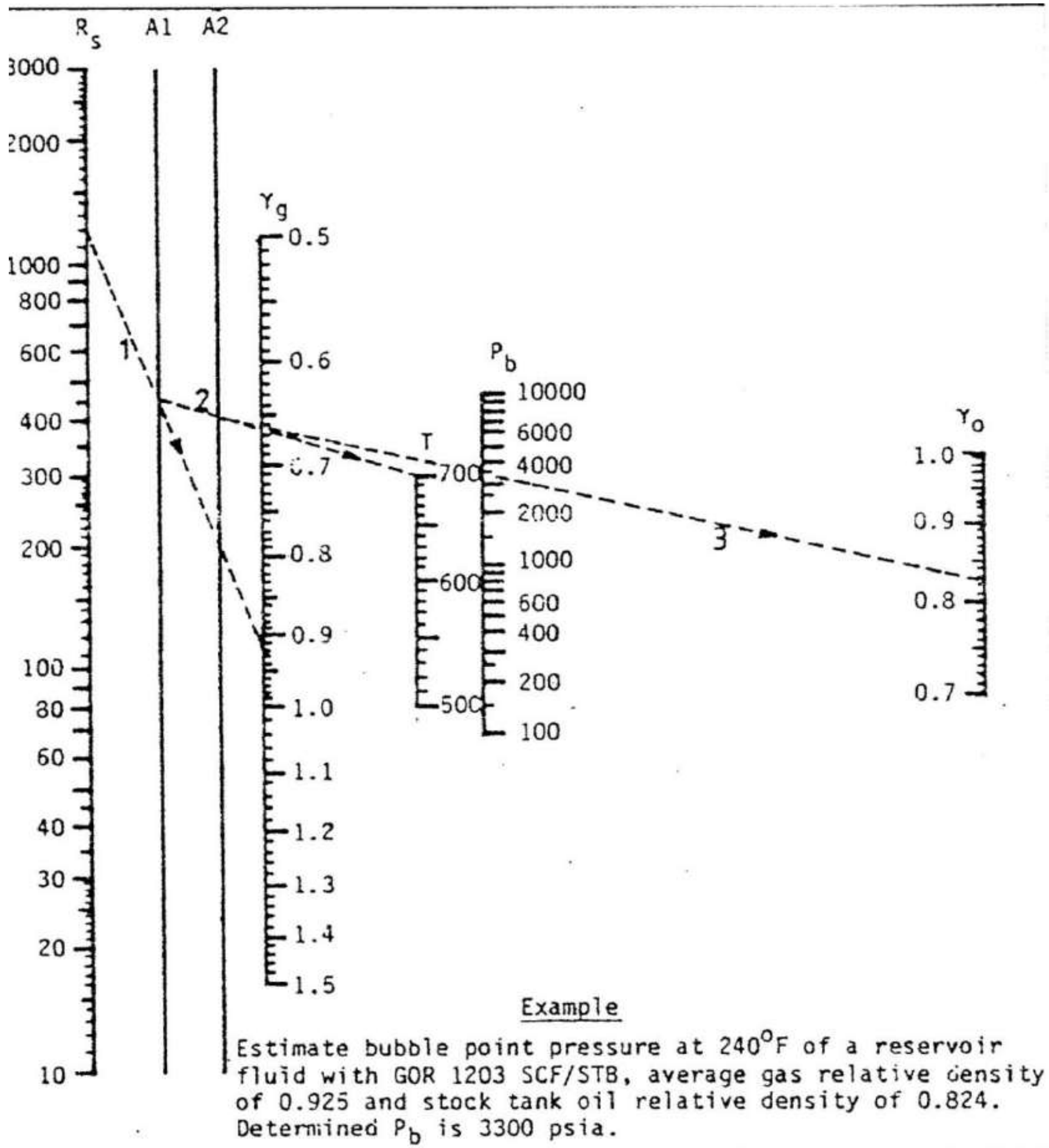
Graphs

Correlation chart for total formation volume factor by Standing 1947



Nomographs

Nomograph correlation for bubble point pressure by Al-Marhoun 1988



Equations

Correlation for bubble point oil formation volume factor by Vasquez & Beggs 1980

$$B_{ob} = 1 + a_1 R_s + a_2 (T - 60)(\gamma_{\mathrm{API}} / \gamma_g) + a_3 R_s (T - 60)(\gamma_{\mathrm{API}} / \gamma_g)$$

Black-oil PVT correlations

1. Oil density
2. Bubble point pressure
3. Solution gas-oil ratio
4. Bubble point oil FVF
5. Total FVF
6. Isothermal oil compressibility
7. Undersaturated oil viscosity
8. Bubble point oil viscosity
9. Dead oil viscosity
10. Surface tension

Oil density

- The oil density is defined as the mass per unit volume at a specified pressure and temperature.

$$\rho_o = \frac{m_o}{v_o}$$

- The relative density of oil is defined as:

$$\gamma_o = \frac{\rho_o}{\rho_w}$$

Oil density

- The relative density of oil at any other temperature T could be calculated using

$$\gamma_{oT} = \frac{\gamma_o}{1 + 0.465791x10^{-3}(T - 60)}$$

- In the petroleum industry, it is common to express gravity in terms of oil API gravity, or:

$$\gamma_{api} = \frac{141.5}{\gamma_O} - 131.5$$

Oil density

- Oil density is required at various pressures and at reservoir temperature for reservoir engineering calculations. An equation for oil density at Pb in equation form is expressed as

$$\gamma_{ob} = \frac{\gamma_o + 2.18x10^{-4} R_s \gamma_g}{B_{ob}}$$

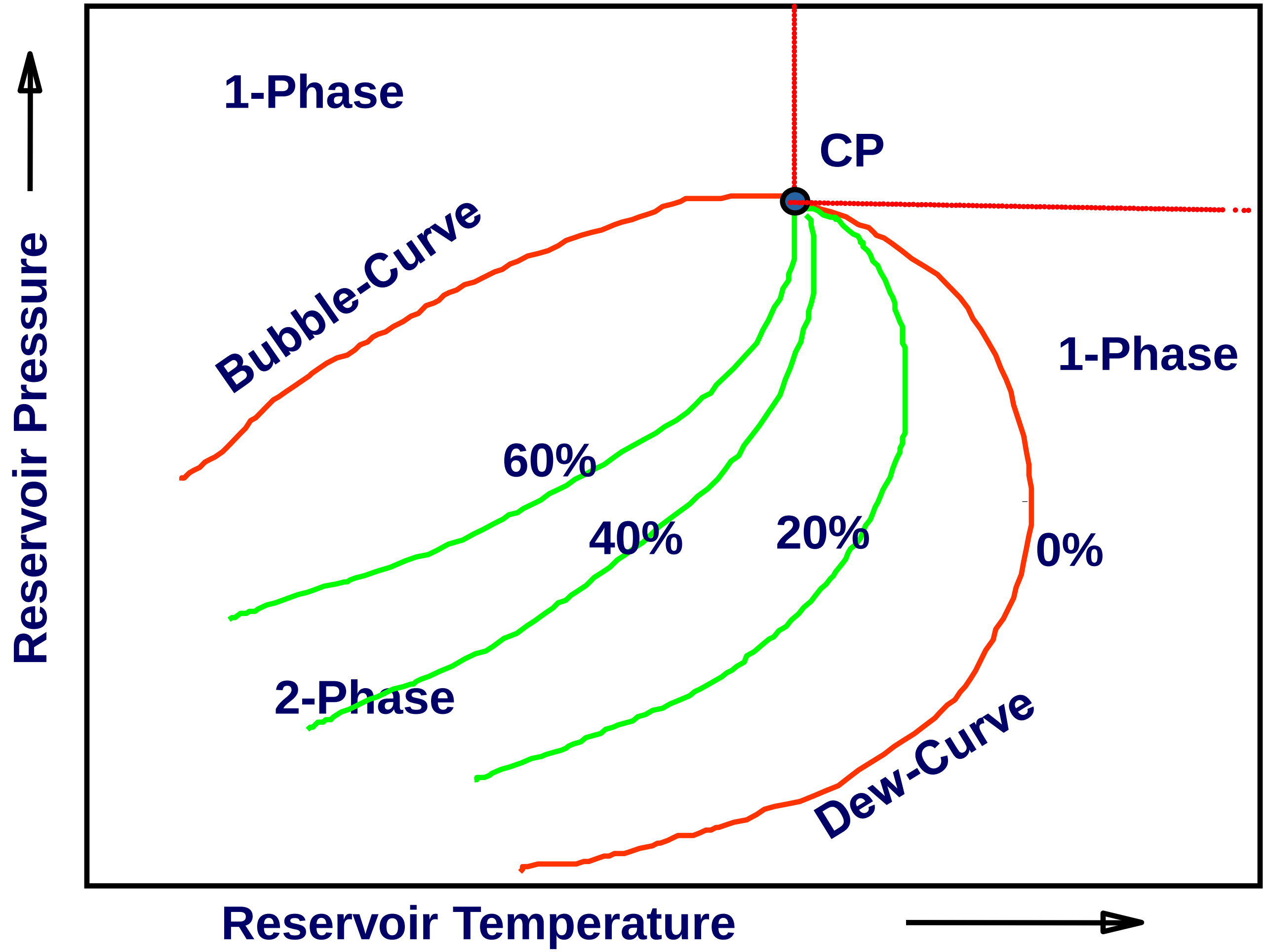
Oil density

- Above bubble point pressure, increased pressure will compress the liquid and increase its density. For the case of $P > P_b$, the oil density is calculated from
- Correlation for calculating average oil compressibility C_o at various conditions is presented later

$$\gamma_o = \gamma_{ob} e^{\bar{c}_o (P - P_b)}$$

Bubble point pressure

Bubble point pressure is the pressure at which the first bubble of gas evolves as the pressure decreases



Bubble point pressure .

- Standing (1947)

$$P_b = a_1 \left(\frac{R_s}{\gamma_g} \right)^{a_2} e^{a_3 T + a_4 \gamma_{api}}$$

where	a_1	=	18
	a_2	=	0.83
	a_3	=	2.09535 E-3
	a_4	=	- 28.78231 E-3

Bubble point pressure ..

- Vasquez and Beggs (1980)

$$P_b = a_1\left(\frac{R_s}{\gamma_g}\right)^{a_2} e^{a_3\gamma_{api}/(T+460)}$$

where

Coefficient	$\gamma_{api} \leq 30$	$\gamma_{api} > 30$
a_1	20.7880	29.7818
a_2	0.9143	0.8425
a_3	-23.5202	-20.1609

Bubble point pressure …

- Al-Marhoun (1988)

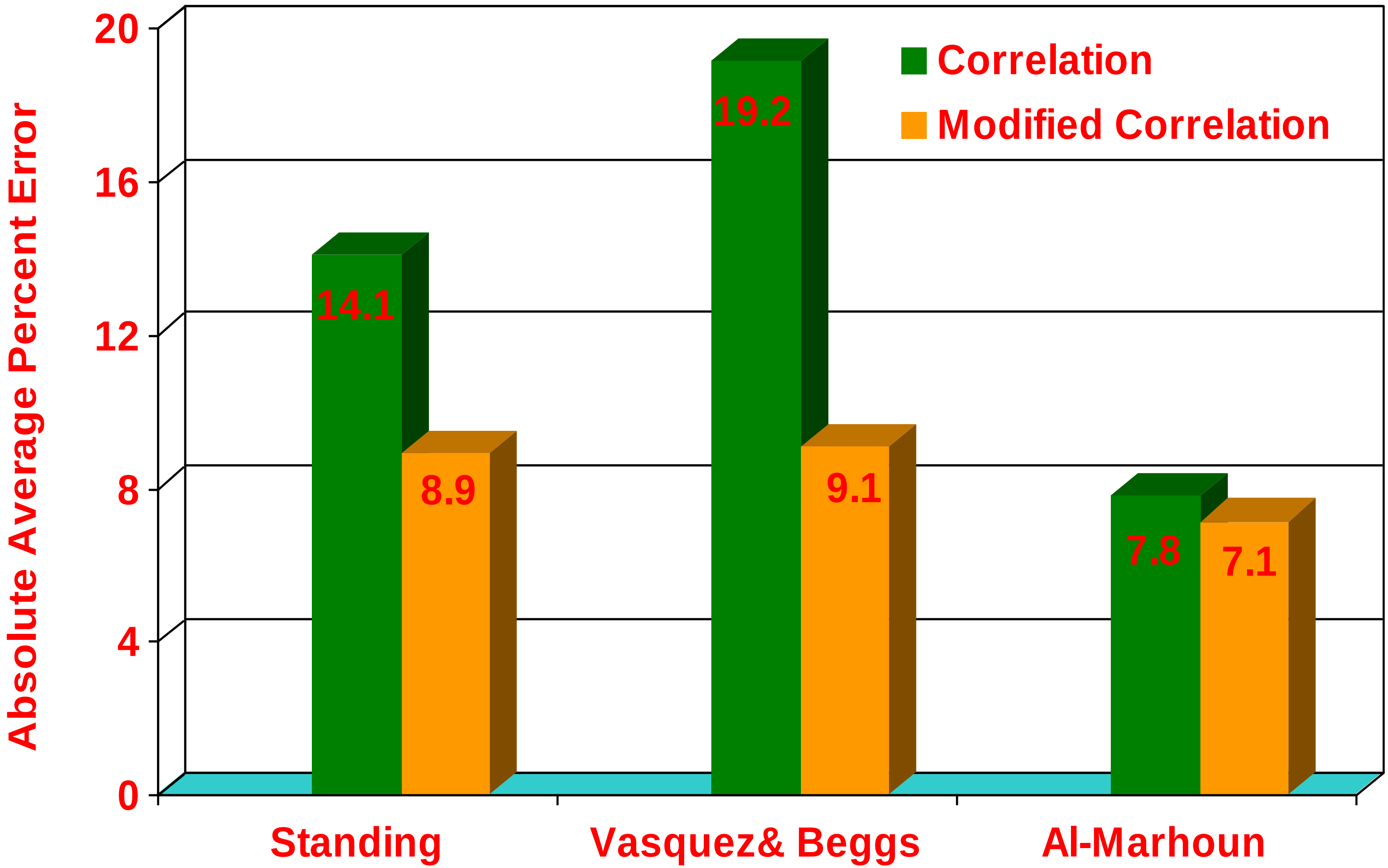
$$P_b = a_1 R_s^{a_2} \gamma_g^{a_3} \gamma_o^{a_4} \left(T + 460\right)^{a_5}$$

where	a_1	=	5.38088 E-3
	a_2	=	0.715082
	a_3	=	-1.87784
	a_4	=	3.14370
	a_5	=	1.32657

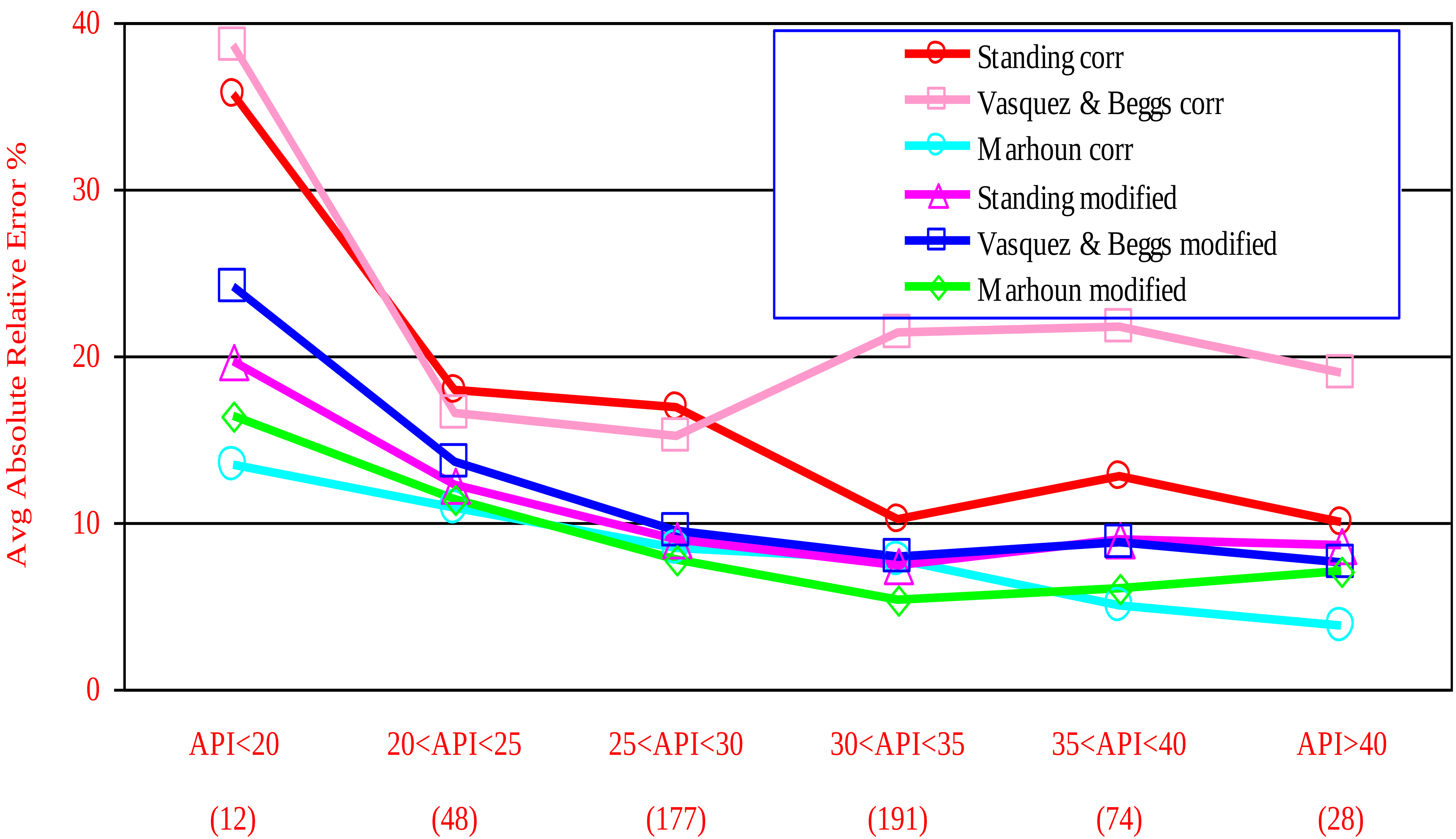
Statistical accuracy of P_b correlations

	ER	EA	E max	STD	R
Correlation					
Standing (1947)	-11.52	14.06	80.86	15.55	
Vasquez & Beggs (1980)	-17.24	19.15	103.90	16.41	
Al-Marhoun (1988)	1.85	7.81	59.03	11.04	
Modified Correlation					
Standing (1947)	-0.81	8.89	53.87	12.59	0.9837
Vasquez & Beggs (1980)	-0.85	9.09	56.25	12.85	0.9777
Al-Marhoun (1988)	-0.60	7.12	56.39	10.37	0.9887

Absolute error of P_b correlations

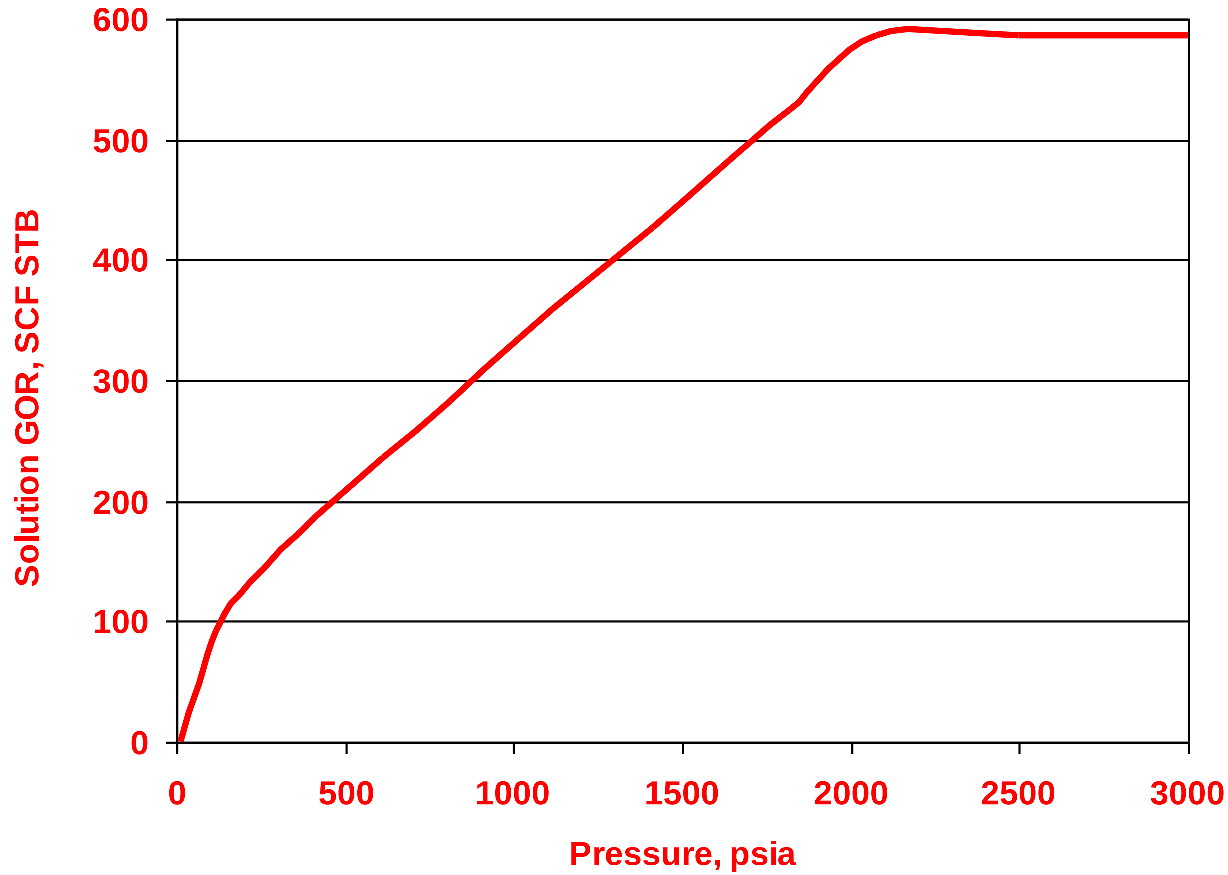


Absolute error versus API gravity



Solution gas-oil ratio

Solution Gas-Oil Ratio is the ratio of gas evolves from solution to oil. It is usually expressed in units of scf/stb.



Typical solution GOR curve

Solution gas-oil ratio .

- Standing (1947)

$$R_s = a_1 \gamma_g P_b^{a_2} e^{a_2 T + a_4 \gamma_{api}}$$

where

a_1	=	30.7343 E-3
a_2	=	1.2048
a_3	=	-2.5245 E-3
a_4	=	34.677 E-3

Solution gas-oil ratio ..

- Vasquez and Beggs (1980)

$$R_s = a_1 \gamma_g P_b^{a_2} e^{a_3 \gamma_{api}/(T+460)}$$

where

Coefficient	$\gamma_{\text{api}} \leq 30$	$\gamma_{\text{api}} > 30$
a_1	0.0362	0.0178
a_2	1.0937	1.1870
a_3	25.7240	23.9310

Solution gas-oil ratio …

- Al-Marhoun (1988)

$$R_s = a_1 \gamma_g^{a_2} P_b^{a_3} \gamma_o^{a_4} \left(T + 460\right)^{a_5}$$

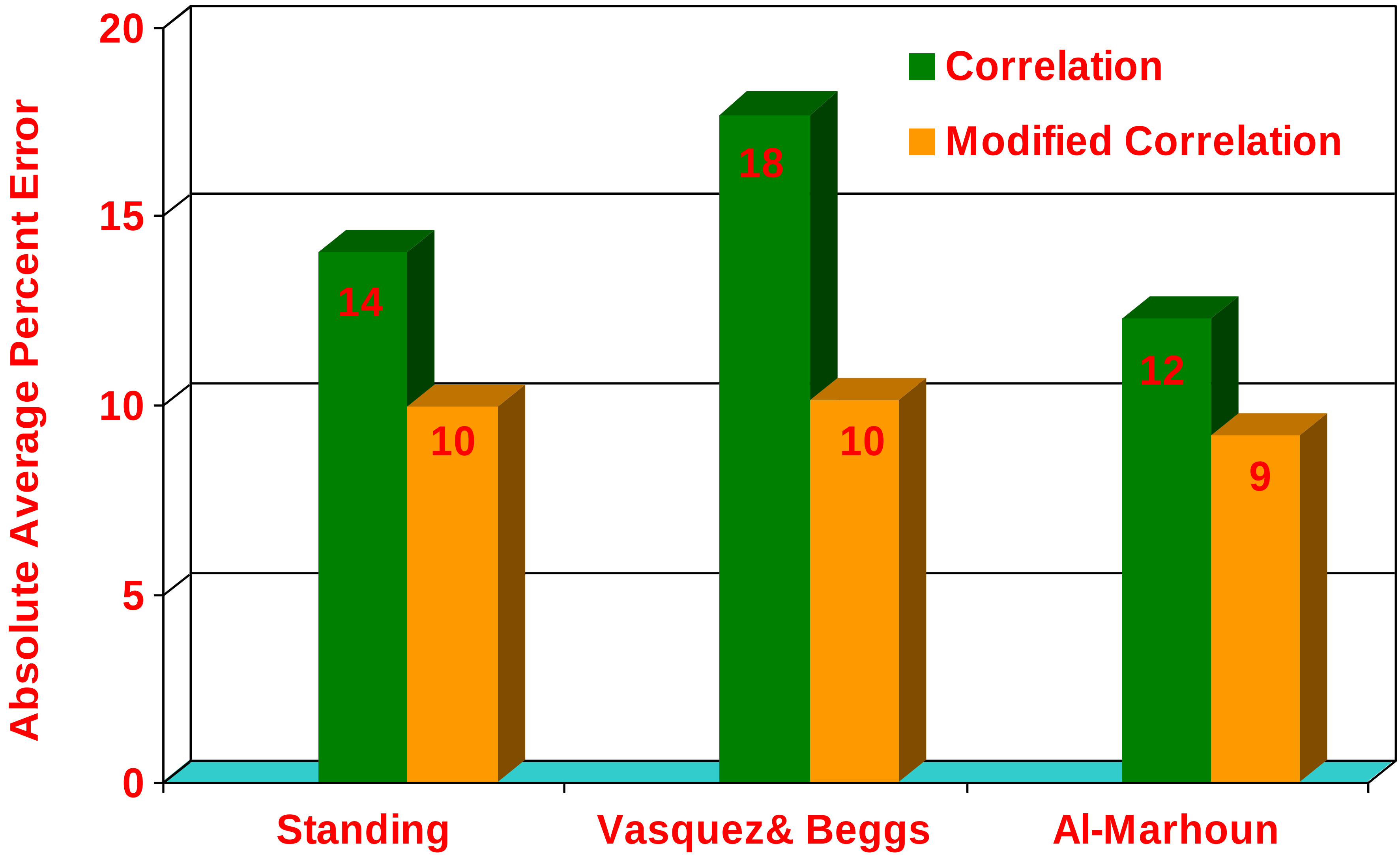
where

a_1	=	1.49028 E+3
a_2	=	2.6260
a_3	=	1.39844
a_4	=	-4.39628
a_5	=	-1.8600

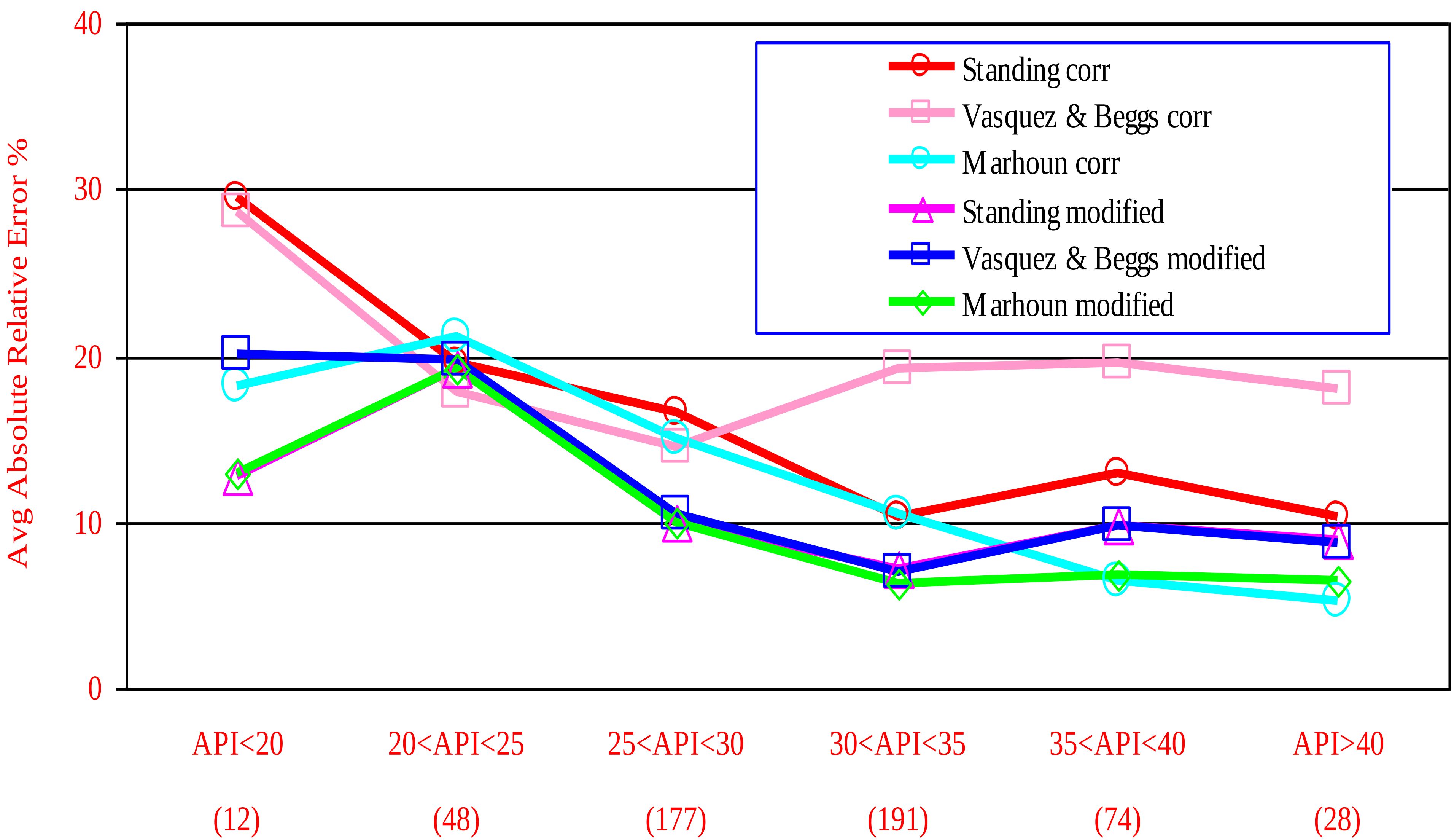
Statistical accuracy of R_s correlations

	ER	EA	E max	STD	R
Correlation					
Standing (1947)	10.07	14.03	104.57	15.84	
Vasquez & Beggs (1980)	14.66	17.67	94.35	15.46	
Al-Marhoun (1988)	-2.37	12.29	237.68	24.64	
Modified Correlation					
Standing (1947)	-1.11	9.96	123.01	16.5	0.9845
Vasquez & Beggs (1980)	-1.153	10.11	91.94	16.10	0.9721
Al-Marhoun (1988)	-1.08	9.20	151.22	17.2	0.9857

Absolute error of R_s correlations

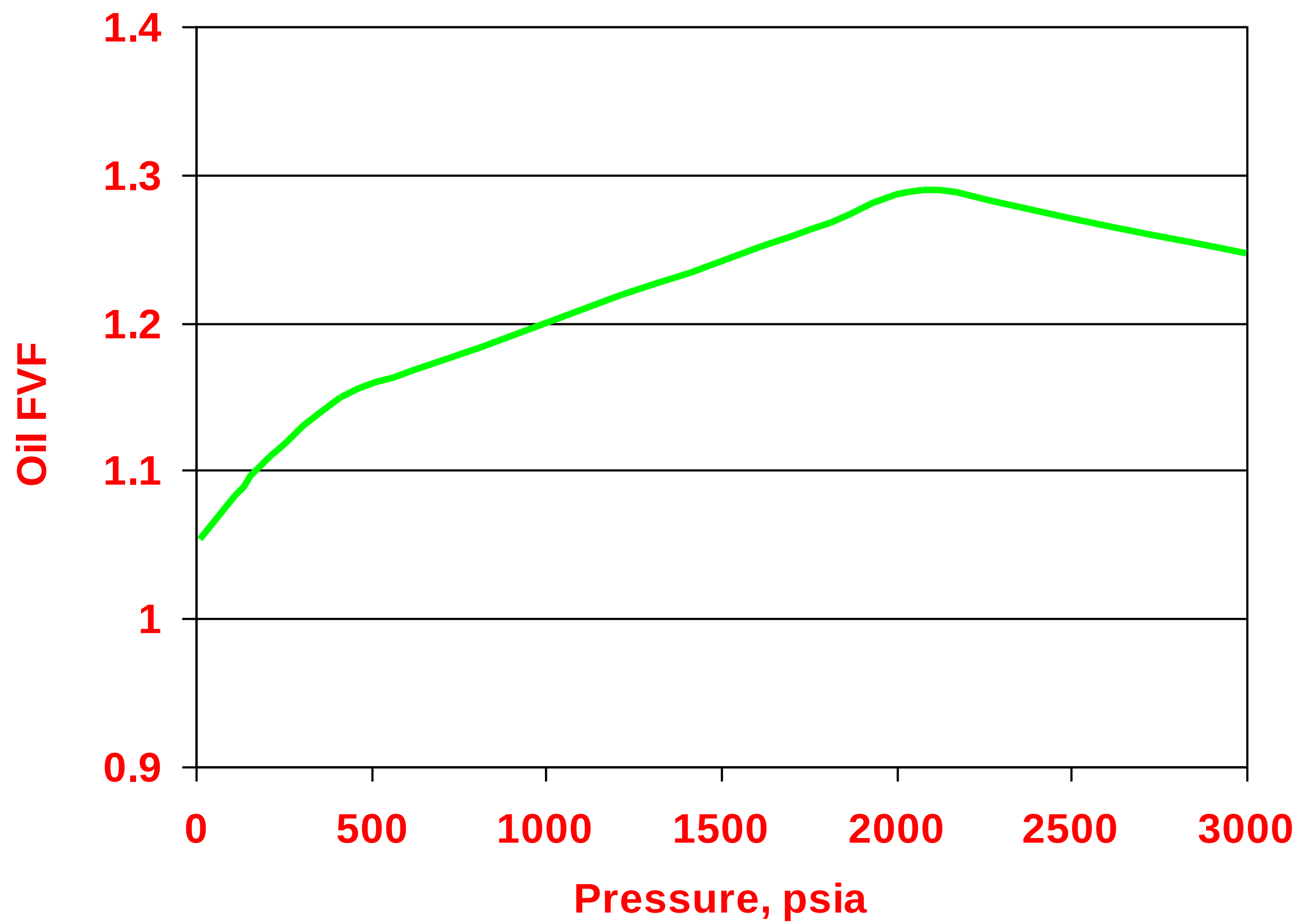


Absolute error versus API gravity



Oil formation volume factor

Oil Formation Volume Factor is the volume at reservoir conditions occupied by one stock tank barrel of oil plus its solution gas.



Typical oil FVF curve

Oil formation volume factor .

- Standing (1947)

$$B_{ob} = a_1 + a_2 [R_s (\gamma_g / \gamma_o)^{a_3} + a_4 T]^{a_5}$$

where

a_1	=	0.9759
a_2	=	0.00012
a_3	=	0.5
a_4	=	1.25
a_5	=	1.2

Oil formation volume factor ..

- Vasquez and Beggs (1980)

$$B_{ob} = 1 + a_1 R_s + a_2 (T - 60)(\gamma_{\mathrm{api}} / \gamma_g) + a_3 R_s (T - 60)(\gamma_{\mathrm{api}} / \gamma_g)$$

where

Coefficient	$\gamma_{\mathrm{api}} \leq 30$	$\gamma_{\mathrm{api}} > 30$
a_1	0.4677 E-3	0.467 E-3
a_2	17.51 E-6	11.00 E-6
a_3	-18.11 E-9	1.337 E-9

Oil formation volume factor …

- Al-Marhoun (1992)

$$B_{ob} = 1 + a_1 R_s + a_2 R_s (\gamma_g / \gamma_o) + a_3 R_s (T - 60)(1 - \gamma_o) + a_4 (T - 60)$$

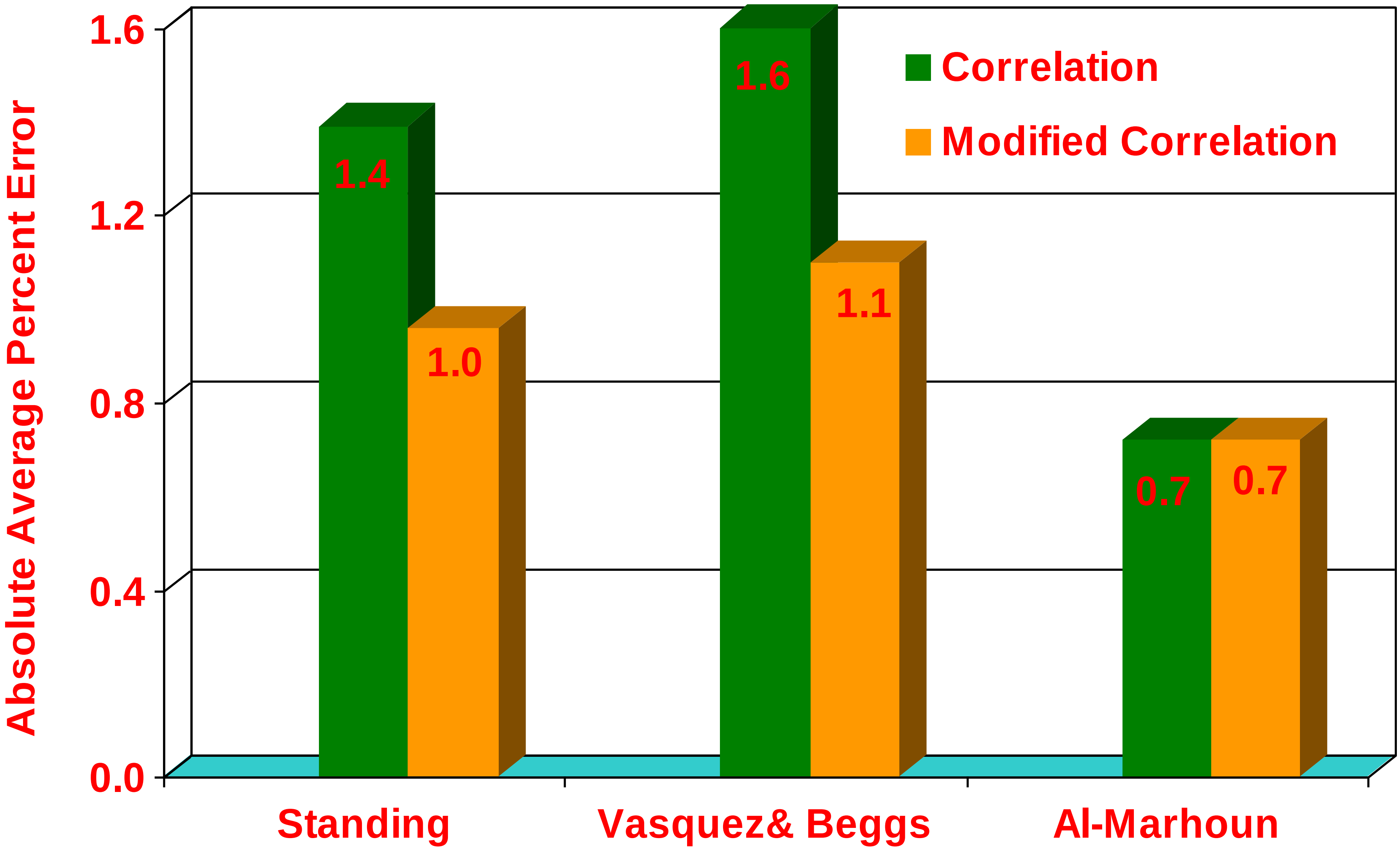
where

a_1	=	0.177342 E-3
a_2	=	0.220163 E-3
a_3	=	4.292580 E-6
a_4	=	0.528707 E-3

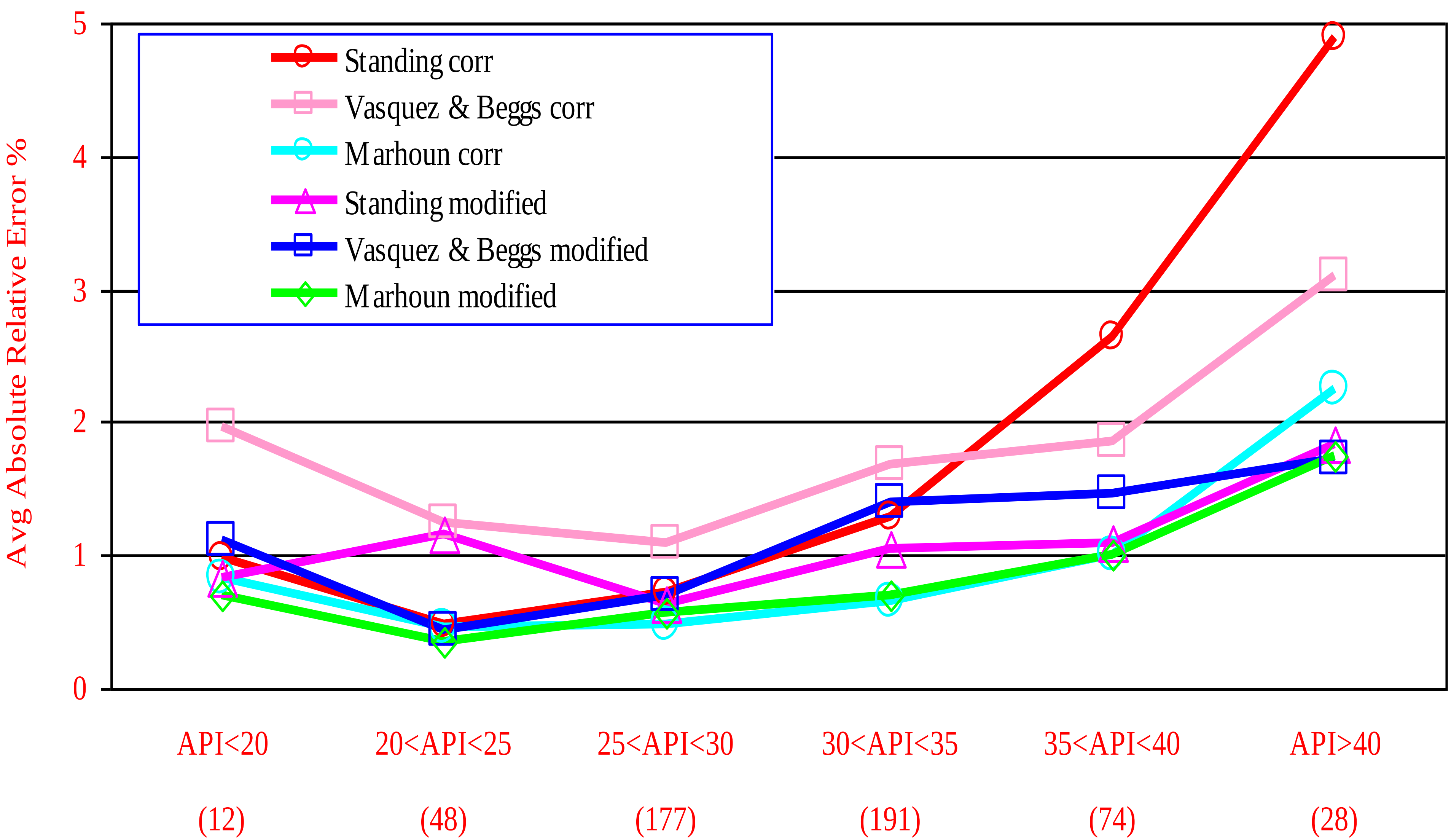
Statistical accuracy of B_{ob} correlations

	ER	EA	E max	STD	R
Correlation					
Standing (1947)	-0.68	1.39	11.79	2.02	
Vasquez & Beggs (1980)	1.00	1.60	16.80	2.03	
Al-Marhoun (1992)	-0.18	0.72	16.82	1.28	
Modified Correlation					
Standing (1947)	-0.02	0.96	9.11	1.31	0.9928
Vasquez & Beggs (1980)	0.082	1.10	10.13	1.49	0.9801
Al-Marhoun (1992)	0.06	0.72	14.33	1.21	0.9912

Absolute error of B_{ob} correlations



Absolute error versus API gravity



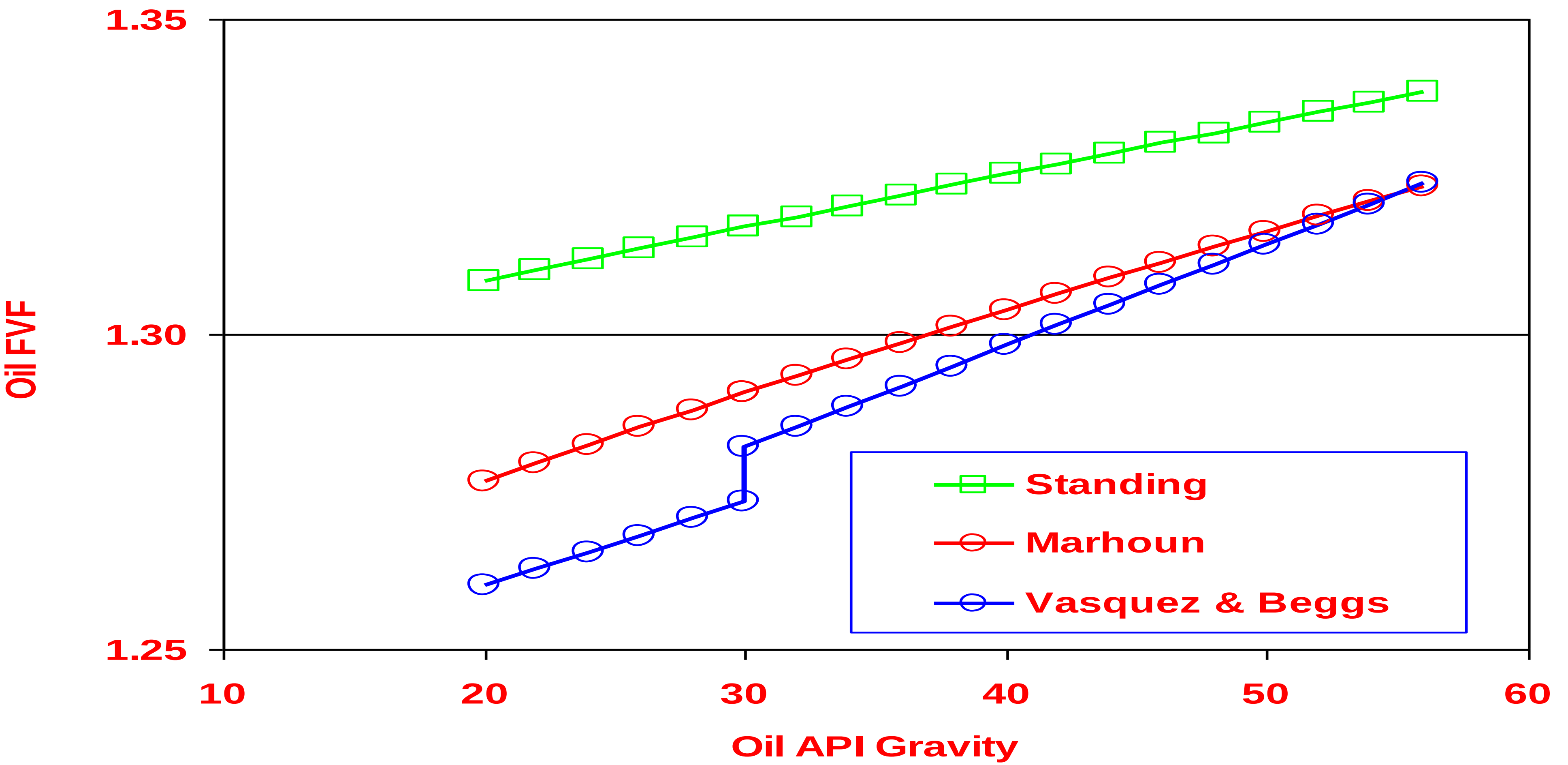
Physical trends of correlations

Trend tests are to check whether the performance of correlation follows physical behavior or not:

- Trend tests on predicted values

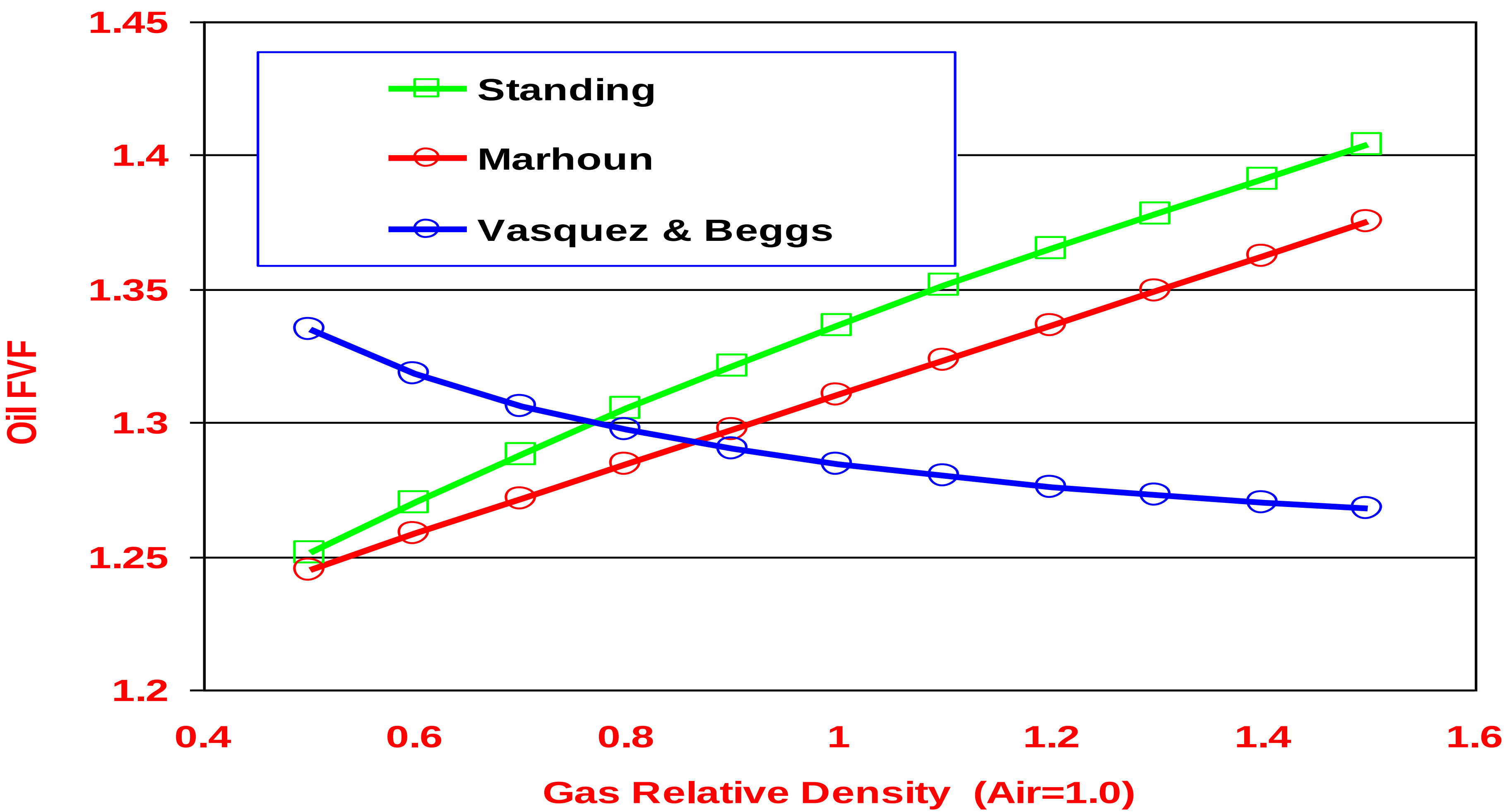
Correlation with two equations

- Modeling physical properties with two equations might produce non-physical trend



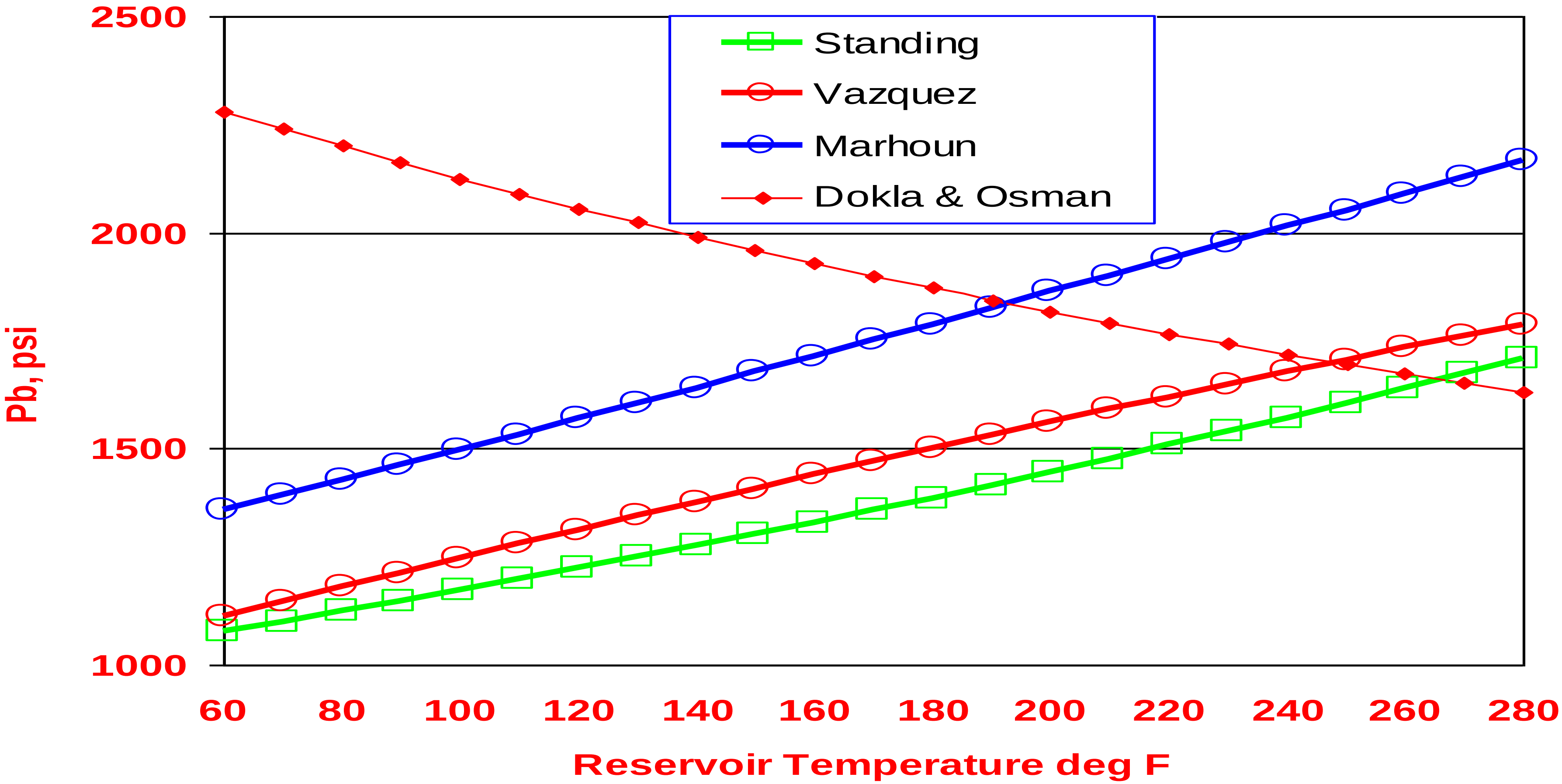
Correlation with non-physical constraint

- Restriction of correlation model gives non-physical trend



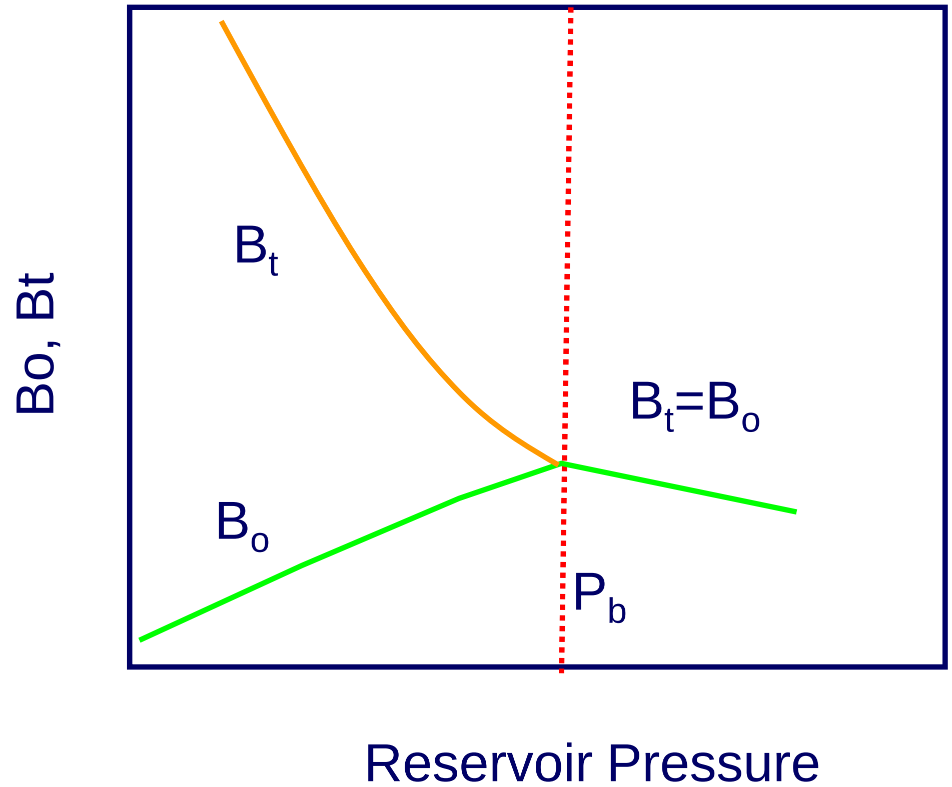
Correlation with limited data

- Correlation development for limited data will give a good fit, but might lead to non-physical trend



Two-phase formation volume factor

The two-phase formation volume factor is the volume of oil plus the volume of gas evolved converted to reservoir conditions per stock tank barrel.



Typical total FVF curve

$$B_t = B_o + B_g (R_{sb} - R_s)$$

Total formation volume factor .

- Standing (1947)

$$\log B_t = a_1 + \frac{a_2}{a_3 + F}$$

$$F = \log(R_s T^{a_4} \gamma_g^{a_5} \gamma_o^{C}) + \frac{a_6}{a_7 + \log P}$$

$$C = 2.9x10^{-0.00027 R_s}$$

where

a_1	=	-5.262	a_5	=	-0.3
a_2	=	-47.4	a_6	=	96.8
a_3	=	-22.32	a_7	=	6.604
a_4	=	0.5			

Total formation volume factor ..

- Glaso (1980)

$$\ln B_t = a_1 + a_2 \ln F + a_3 (\ln F)^2$$

$$F = R_s T^{a_4} \gamma_g^{a_5} P^{a_6} \gamma_o^{C}$$

$$C = 2.9x10^{-0.00027 R_s}$$

where

a_1	=	0.184518	a_4	=	0.5
a_2	=	0.47257	a_5	=	-0.3
a_3	=	75.354436 E-3	a_6	=	-1.1089

Total formation volume factor …

- Al-Marhoun (1992)

$$B_t = B_{ob}(p/p_b)^d$$

and

$$d = a_1(T+460) + a_2 \ln \gamma_g + a_3\gamma_o + a_4 \ln \gamma_o + a_5(p/p_b) + a_6 \ln(p/p_b)$$

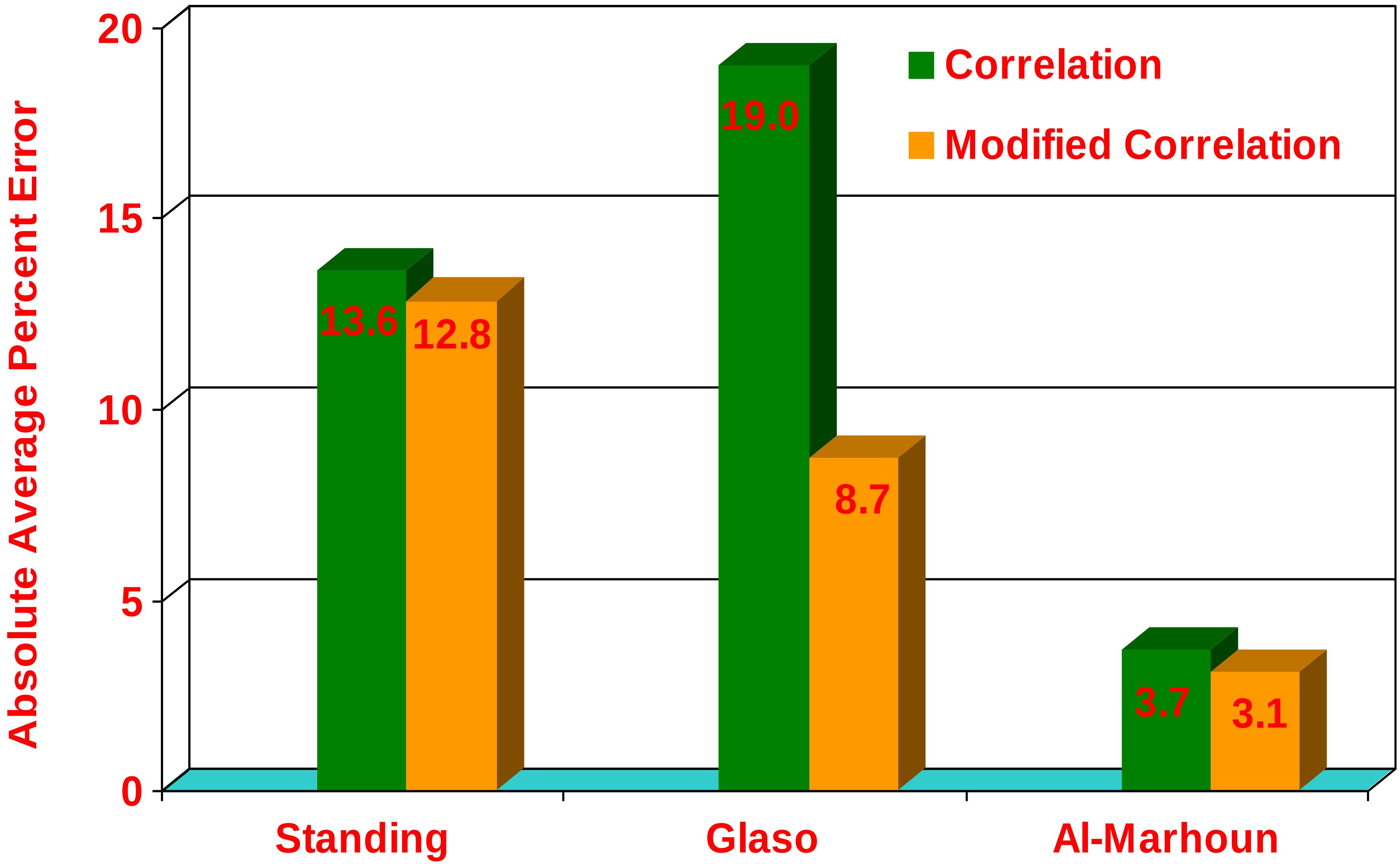
where

a_1	=	-0.352796 E-3	a_4	=	1.64925964
a_2	=	-0.35328914	a_5	=	0.36432305
a_3	=	-0.24964270	a_6	=	0.08685097

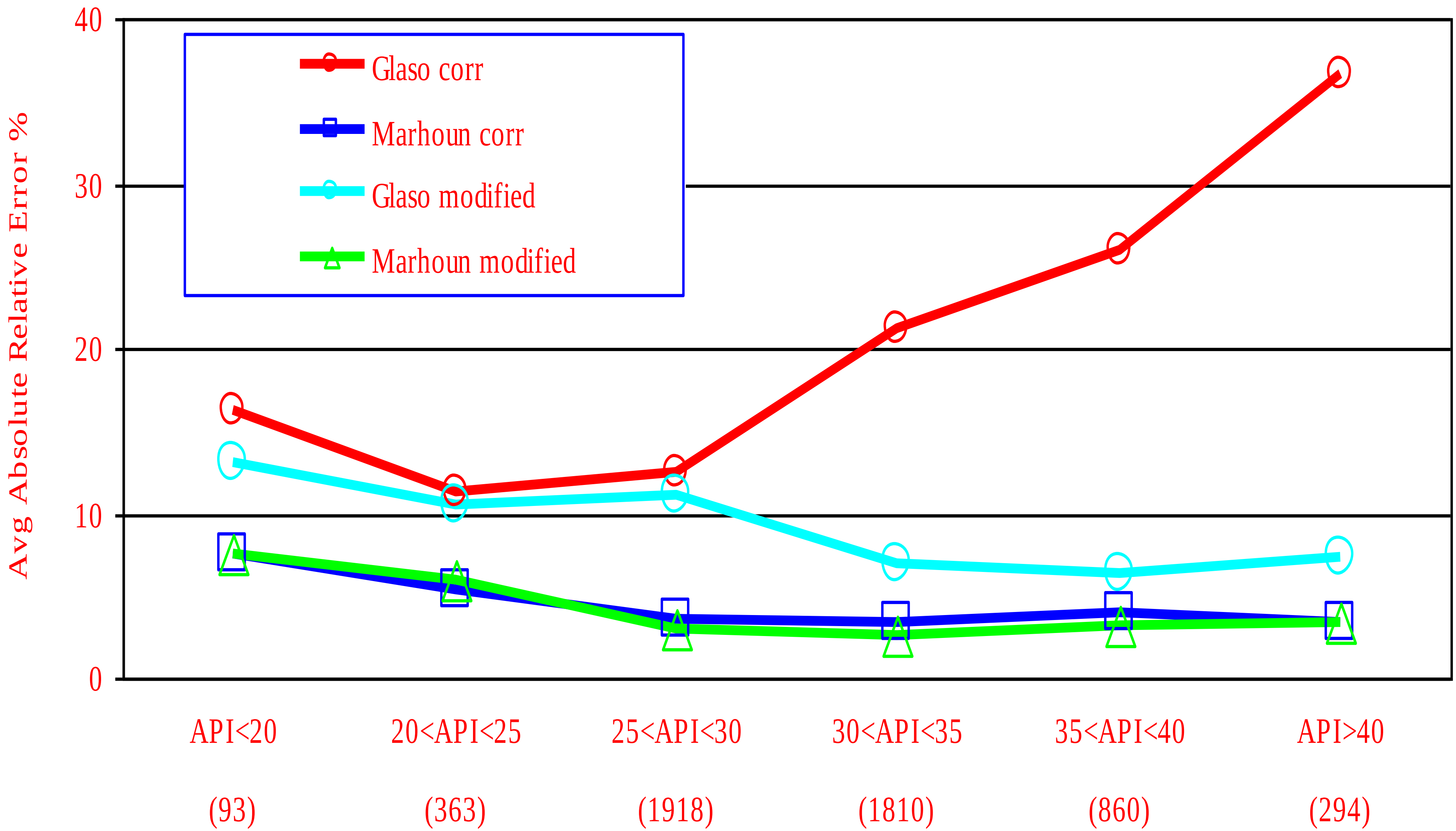
Statistical accuracy of B_t correlations

	ER	EA	E max	STD	R
Correlation					
Standing (1947)	-9.69	13.60	182.07	20.79	
Glaso (1980)	12.45	18.98	128.97	20.01	
Al-Marhoun (1992)	1.92	3.68	87.49	6.69	
Modified Correlation					
Standing (1947)	-2.88	12.83	216.28	20.05	0.9866
Glaso (1980)	-1.06	8.70	195.90	17.06	0.9657
Al-Marhoun (1992)	-0.21	3.13	84.82	6.44	0.8707

Absolute error of B_t correlations



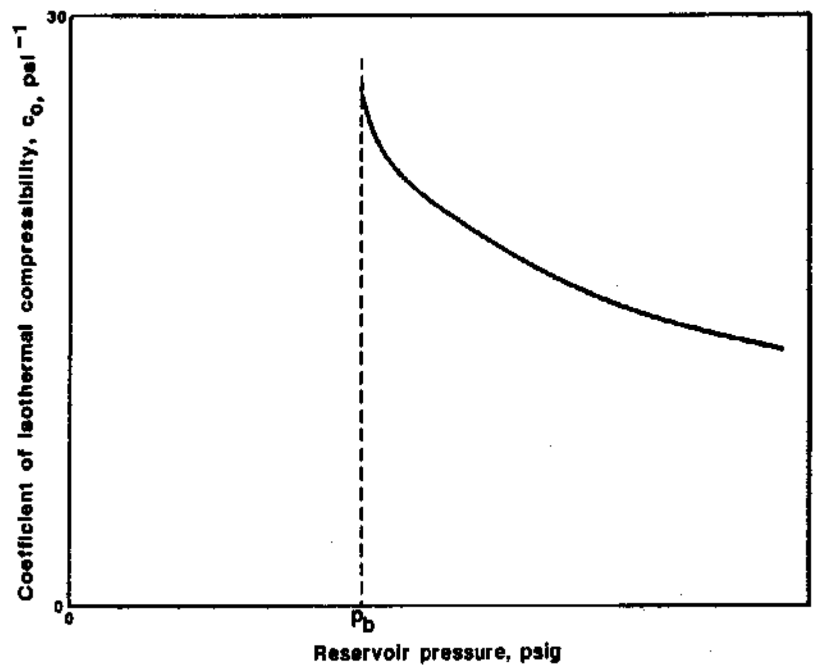
Absolute error versus API gravity



Isothermal oil compressibility

- It is defined as the unit change of volume with pressure at constant temperature.
- C_o is used in the calculation of oil density and FVF above Pb as shown.

$$c_o = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$



Typical C_o curve above P_b

$$\gamma_{op} = \gamma_{ob} e^{\bar{c}_o (P - P_b)}$$

$$B_o = B_{ob} e^{\bar{c}_o (P_b - P)}$$

Isothermal oil compressibility

- To calculate undersaturated oil density or FVF above bubble point pressure the average oil compressibility is used $\overline{C_o}$

$$\bar{c}_o = \frac{1}{p - p_b} \int_{P_b}^{P} c_o(p)dp$$

- To avoid the calculation involved, $\overline{C_o}$ can be calculated at average pressure $\overline{P}$ as follows:

$$\bar{c}_o = c_o(\overline{P})$$

where

$$\overline{P} = \left(\frac{P + P_b}{2} \right)$$

Isothermal oil compressibility .

- Vasquez & Beggs (1980)

$$C_O = (a_1 + a_2 R_s + a_3 T + a_4 \gamma_g + a_5 \gamma_{api}) / p$$

where

a_1	=	-14.33 E-3
a_2	=	50 E-6
a_3	=	0.172 E-3
a_4	=	-11.80 E-3
a_5	=	0.1261 E-3

Isothermal oil compressibility ..

- Petrosky & Farshad (1993)

$$C_o = a_1 R_s^{a_2} \gamma_g^{a_3} \gamma_{api}^{a_4} T^{a_5} P^{a_6}$$

where

a_1	=	0.1705 E-6	a_4	=	0.3272
a_2	=	0.69357	a_5	=	0.6729
a_3	=	0.1885	a_6	=	-0.5906

Isothermal oil compressibility …

- Al-Marhoun (2003)

$$\ln c_o = a_1 + a_2/\gamma_{ob} + a_3(P - P_b)/\gamma_{ob}^3 + a_4/(T + 460)$$

and

$$\gamma_{ob} = (\gamma_o + 2.18x10^{-4} R_s \gamma_g)/B_{ob}$$

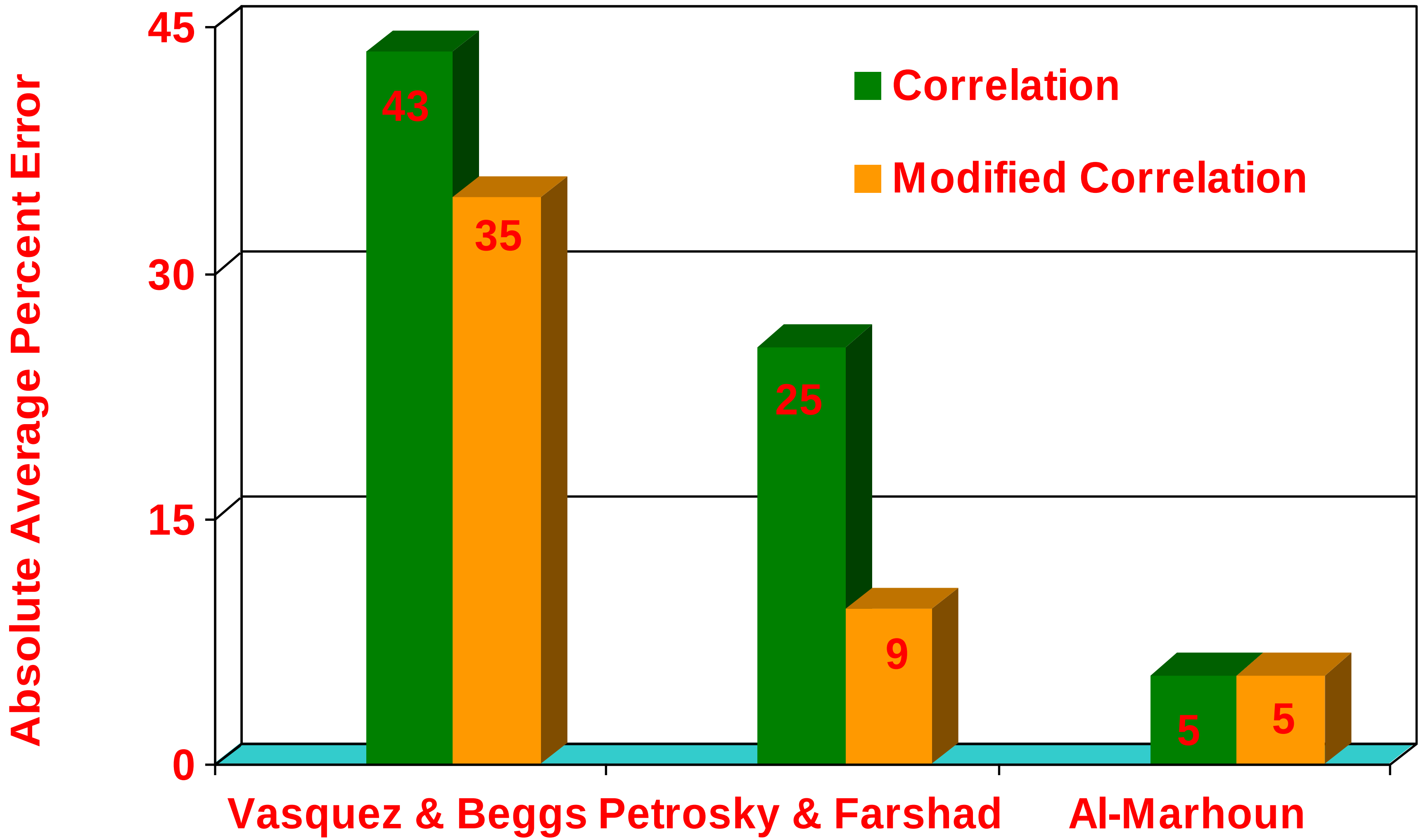
where

a_1	=	-14.1042
a_2	=	2.7314
a_3	=	-56.0605 E-6
a_4	=	-580.8778

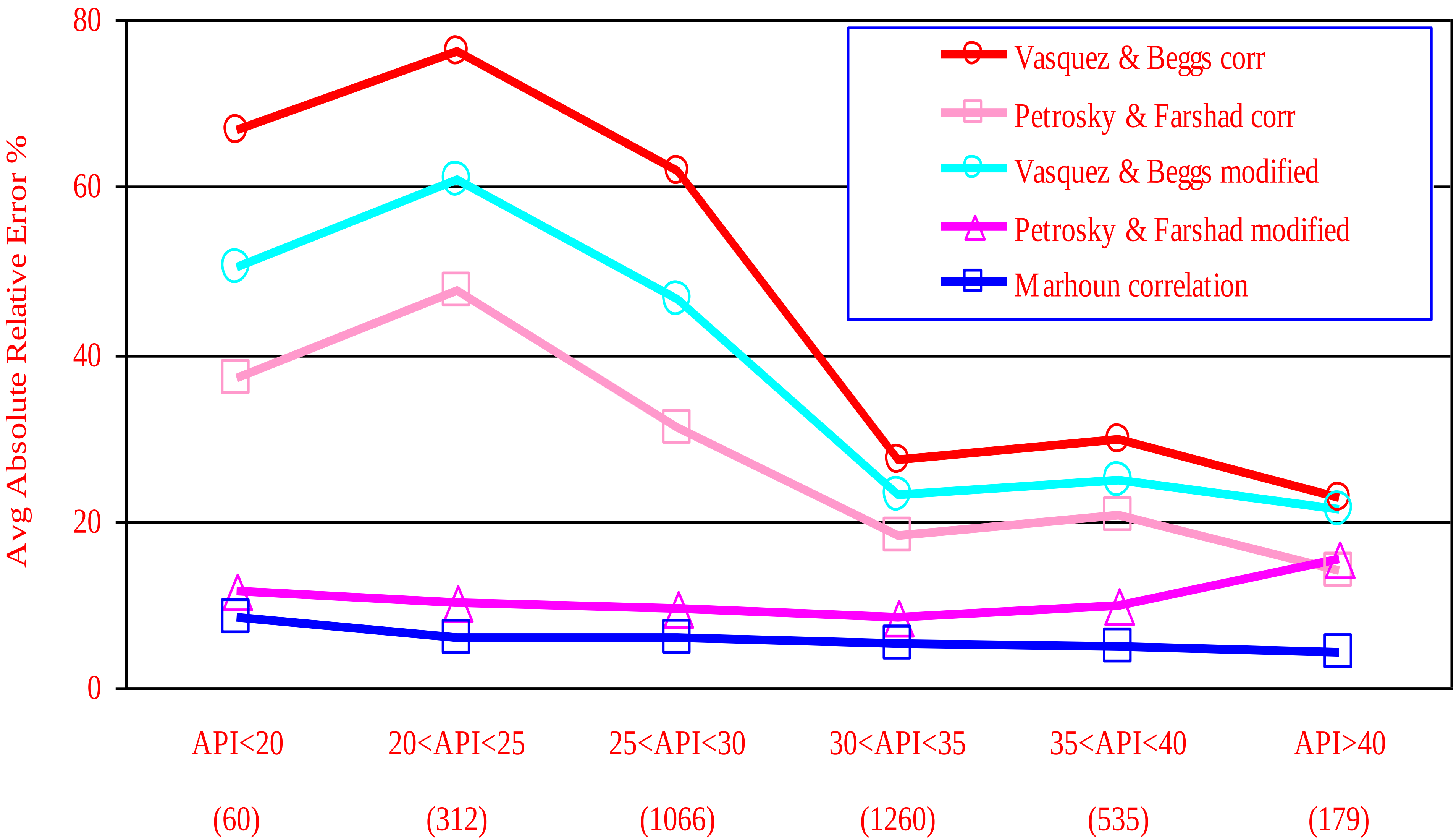
Statistical accuracy of C_o correlations

	ER	EA	E max	STD	R
Correlation					
Vasquez & Beggs (1980)	11.56	43.42	429.76	57.96	
Petrosky & Farshad (1993)	6.13	25.45	138.08	31.74	
Al-Marhoun (2003)	-0.25	5.46	26.87	7.06	
Modified Correlation					
Vasquez & Beggs (1980)	17.84	34.53	244.77	40.33	0.3506
Petrosky & Farshad (1993)	-0.73	9.47	73.18	12.12	0.9222
Al-Marhoun (2003)	-0.25	5.46	26.87	7.06	0.9829

Absolute error of C_o correlations

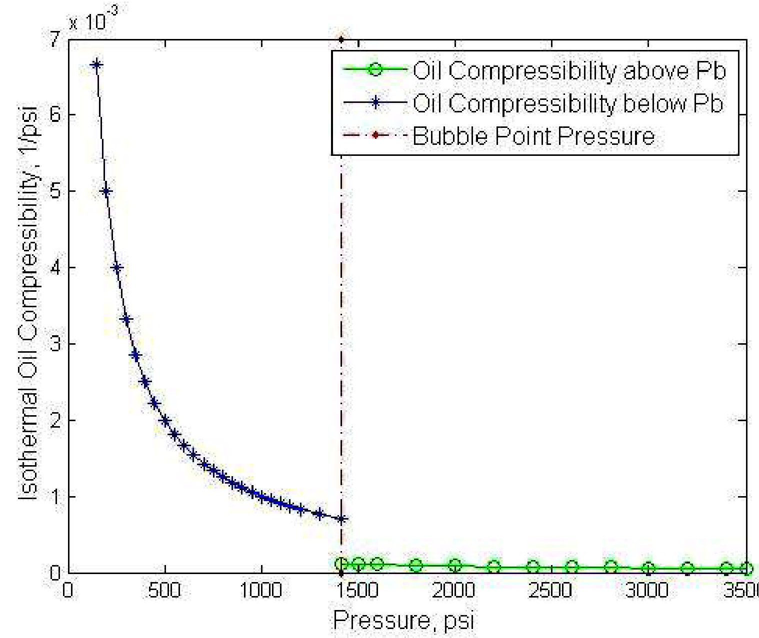


Absolute error versus API gravity



Oil compressibility below P_b

- It is defined as the unit change of volume with pressure at constant temperature
- Below bubble point, volume occupied by gas evolved from the oil during differential change in pressure must be taken into account in the calculation of oil compressibility The defining equation is:



Typical C_o curve below P_b

$$c_o = -\frac{1}{B_o}\left(\left(\frac{\partial B_o}{\partial p}\right)_T - B_g\left(\frac{\partial R_s}{\partial p}\right)_T\right)$$

Oil compressibility below P_b .

- McCain, Rollins and Villena (1988)

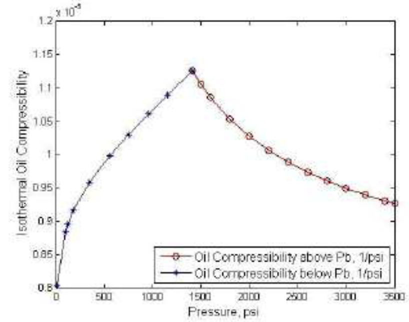
$$\ln c_o = a_1 + a_2 \ln P + a_3 \ln P_b + a_4 \ln T + a_5 \ln \gamma_{api} + a_6 \ln R_{sb}$$

where

a_1	=	-7.573	a_4	=	1.402
a_2	=	-1.450	a_5	=	0.256
a_3	=	-0.383	a_6	=	0.449

Oil compressibility below P_b ..

- Al-Marhoun (2009)



- Al-Marhoun (2003) developed an equation to estimate co above Pb

$$\ln c_o = a_1 + a_2 / \gamma_{ob} + a_3 (P - P_b) / \gamma^3_{ob} + a_4 / (T + 460)$$

- This equation can be used for one point estimation of co at any saturation pressure provided oil relative density is correct:

$$\ln c_{ob} = a_5 + a_2 / \gamma_{ob} \qquad \gamma_{ob} = \frac{\gamma_o + 2.18x10^{-4} R_s \bar{\gamma}_g}{B_{ob}}$$

Oil compressibility below P_b ..

- Any point below the original $\mathbf{P_b}$ is a new saturation pressure for a new fluid of different composition, then

$$\ln c_{op} = a_5 + a_2 / \gamma_{op} \qquad \gamma_{op} = \frac{\gamma_o + 2.18x10^{-4} R_s \bar{\gamma}_g}{B_{op}}$$

- By combining equations, the co at saturation pressure can be calculated in term of co at the original Pb and relative live oil densities as follows:

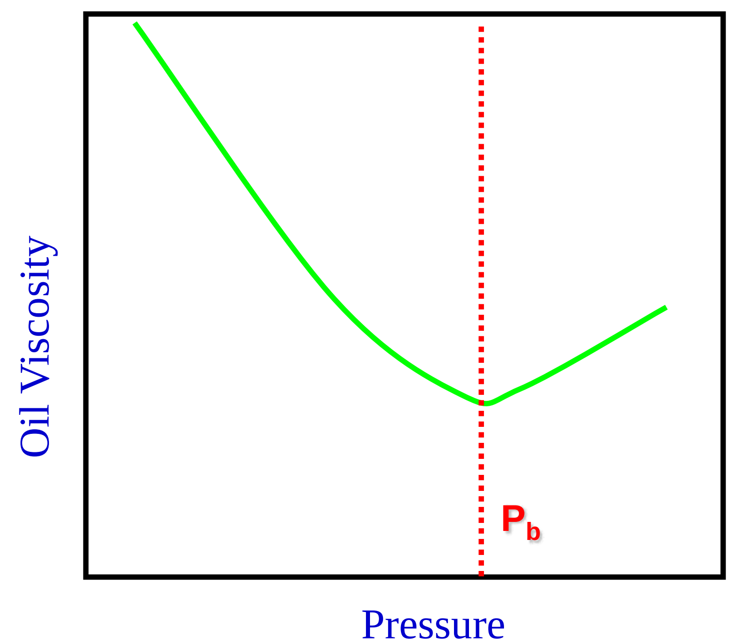
$$\ln \ c_{op} = \ln \ c_{ob} + a_2 \left(\frac{1}{\gamma_{op}} - \frac{1}{\gamma_{ob}} \right) \qquad a_2 = 2.7314$$

Oil viscosity

- Oil viscosity is a measure of the resistance to flow exerted by a fluid. In equation form, relation between shear stress and rate of angular deformation of flow of fluids

$$\mu_o = \frac{\tau}{dv/dy}$$

- Four viscosity types
  - Dead Oil Viscosity
  - Oil Viscosity below P_b
  - Oil Viscosity at P_b
  - Oil Viscosity above P_b



Typical viscosity curve

Oil viscosity above P_b .

- Beal (1946)

$$\mu_a = \mu_{ob} + (P - P_b)(a_1 \mu_{ob}^{a_2} + a_3 \mu_{ob}^{a_4})$$

where

a_1	=	24 E-6
a_2	=	1.60
a_3	=	38 E-6
a_4	=	0.56

Oil viscosity above P_b ..

- Labedi (1992)

$$\mu_o = \mu_{ob} + m\left(p - p_b\right)$$

$$\ln m = a_1 + a_2 \gamma_{api} + a_3 \ln \mu_{od} + a_4 \ln p_b$$

where

a_1	=	-5.728832
a_2	=	-45.360926 E-3
a_3	=	0.9036
a_4	=	-0.3849

Oil viscosity above P_b …

- Al-Marhoun (2004)

$$\ln \mu_o = \ln \mu_{\mathrm{ob}} + \alpha \; \gamma_{ob}^{\;2}\left(p - p_{\mathrm{b}}\right)$$

and

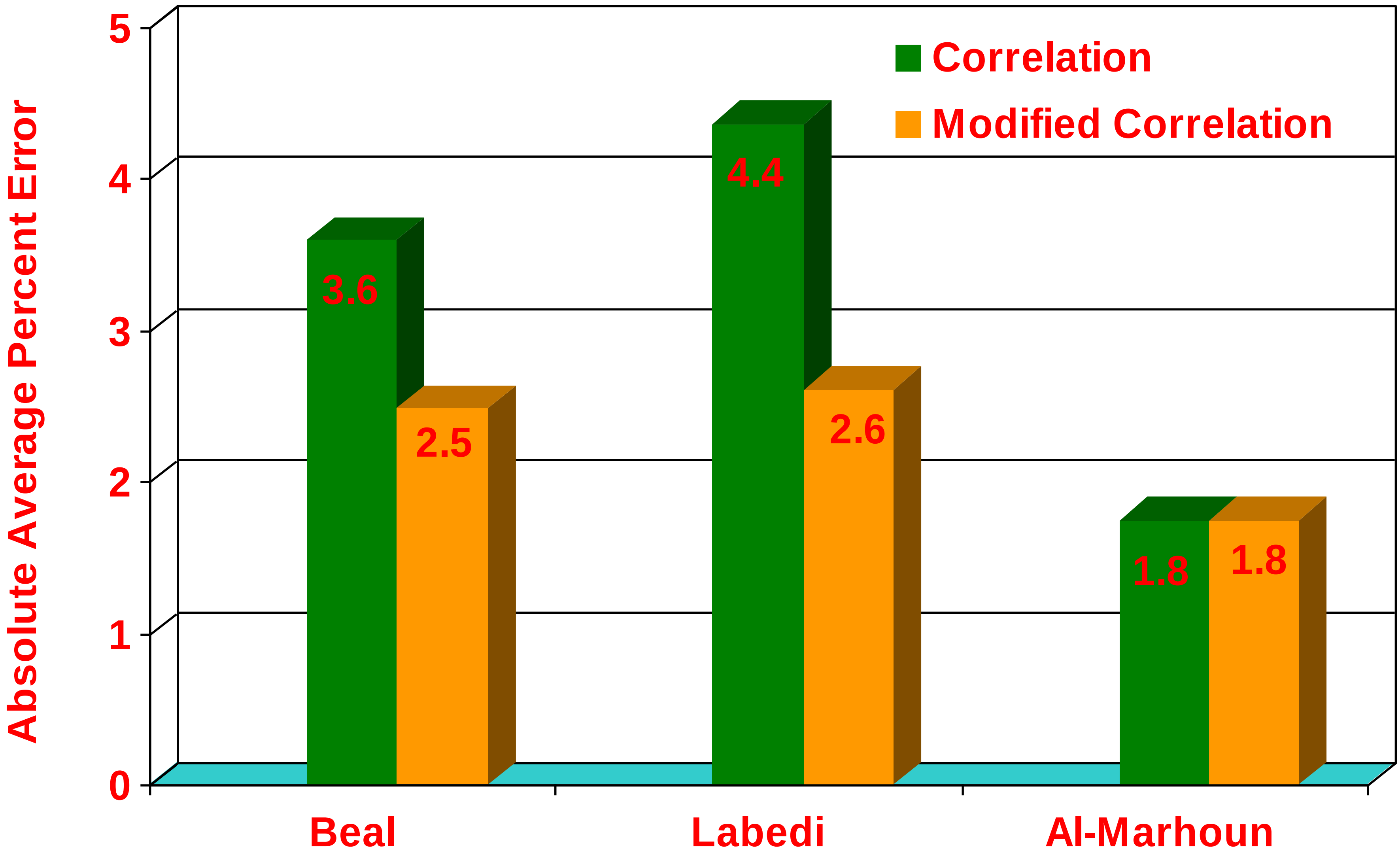
$$\gamma_{ob} = (\gamma_o + 2.18x10^{-4} R_s \gamma_g) / B_{ob}$$

where α = 0.151292 E-3

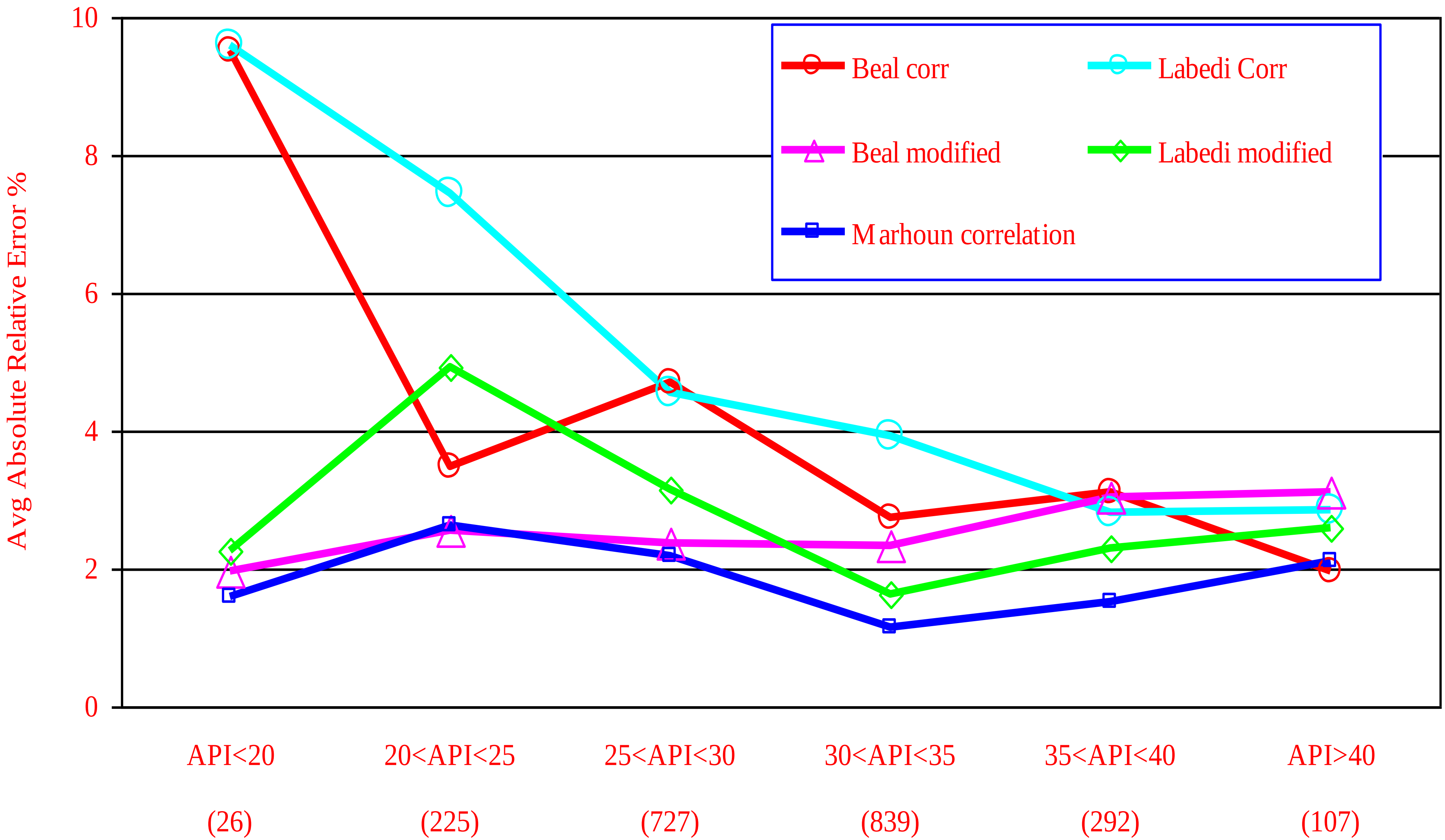
Statistical accuracy of μ_a correlations

	ER	EA	E max	STD	R
Correlation					
Beal (1946)	2.53	3.54	41.81	4.81	
Labedi (1992)	-3.59	4.36	76.78	6.03	
Al-Marhoun (2003)	0.36	1.75	27.21	2.87	
Modified Correlation					
Beal (1946)	-1.48	2.49	25.13	3.18	0.9981
Labedi (1992)	-0.02	2.61	48.89	4.40	0.9970
Al-Marhoun (2003)	0.36	1.75	27.21	2.87	0.9979

Absolute error of μ_a correlations



Absolute error versus API gravity



Oil viscosity at P_b .

- Chew and Connally (1959)

$$\mu_{ob} = \alpha \quad \mu_{od}{}^{\beta}$$

and

$$\alpha = a_1 + a_2 e^{a_3 R_s}$$

$$\beta = a_4 + a_5 e^{a_6 R_s}$$

where

a_1	=	0.2	a_4	=	0.43
a_2	=	0.8	a_5	=	0.57
a_3	=	-1.86509 E-3	a_6	=	-1.65786 E-3

Oil viscosity at P_b ..

- Beggs and Robinson (1975)

$$\mu_{ob} = \alpha \quad \mu_{od}{}^{\beta}$$

where

$$\alpha = a_1 (R_s + a_2)^{a_3}$$

$$\beta = a_4 (R_s + a_5)^{a_6}$$

where

a_1	=	10.715	a_4	=	5.44
a_2	=	100	a_5	=	150
a_3	=	-0.515	a_6	=	-0.338

Oil viscosity at P_b …

- Labedi (1992)

$$\ln \mu_{ob} = a_1 + a_2 \gamma_{api} + a_3 \ln \mu_{od} + a_4 \ln p_b$$

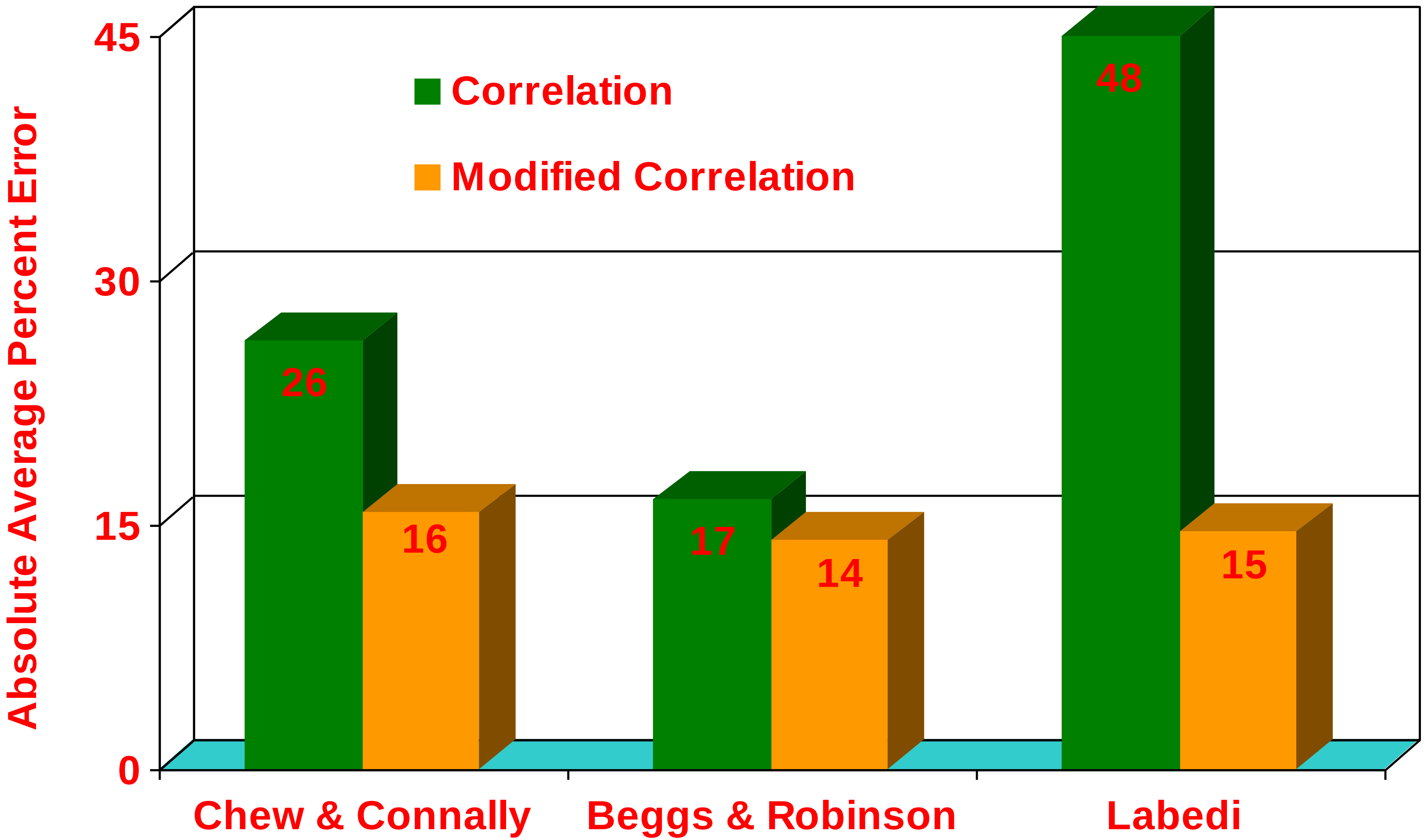
where

a_1	=	5.397259
a_2	=	-0.081557
a_3	=	0.6447
a_4	=	-0.426

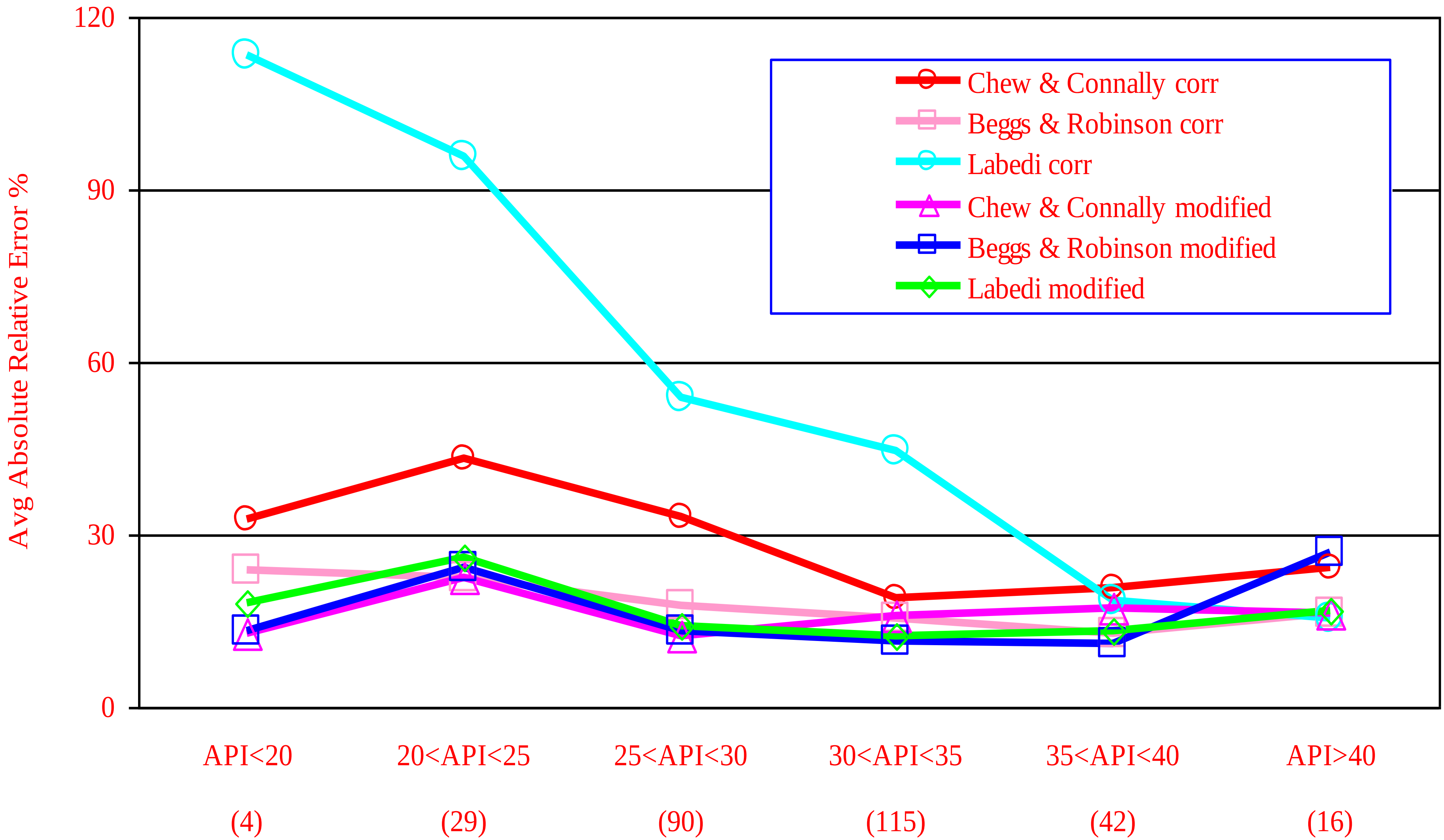
Statistical accuracy of μ_{ob} correlations

	ER	EA	E max	STD	R
Correlation					
Chew & Connally (1959)	-25.76	26.27	333.97	25.92	
Beggs & Robinson (1975)	9.78	16.50	248.25	21.37	
Labedi (1992)	-46.77	47.90	420.39	41.70	
Modified Correlation					
Chew & Connally (1959)	4.49	15.71	236.55	22.85	0.9809
Beggs & Robinson (1975)	-8.83	14.04	240.13	21.15	0.9804
Labedi (1992)	-1.77	14.57	182.45	20.90	0.9666

Absolute error of μ_{ob} correlations



Absolute error versus API gravity



Dead oil viscosity .

- Beggs and Robinson (1975)

$$\ln(\ln(\mu_{od} + 1)) = a_1 + a_2\,\gamma_{api} + a_3 \ln T$$

where

a_1	=	7.816432
a_2	=	-0.04658
a_3	=	-1.163

Dead oil viscosity ..

- Glaso (1980)

$$\ln \mu_{od} = a_1 + a_2 \ln T + a_3 \ln(\ln \gamma_{api}) + a_4 (\ln T) \ln(\ln \gamma_{api})$$

where

a_1	=	54.56805426
a_2	=	-7.179530398
a_3	=	-36.447
a_4	=	4.478878992

Dead oil viscosity …

- Labedi (1992)

$$\ln \mu_{od} = a_1 + a_2 \ln \gamma_{api} + a_3 \ln T$$

where

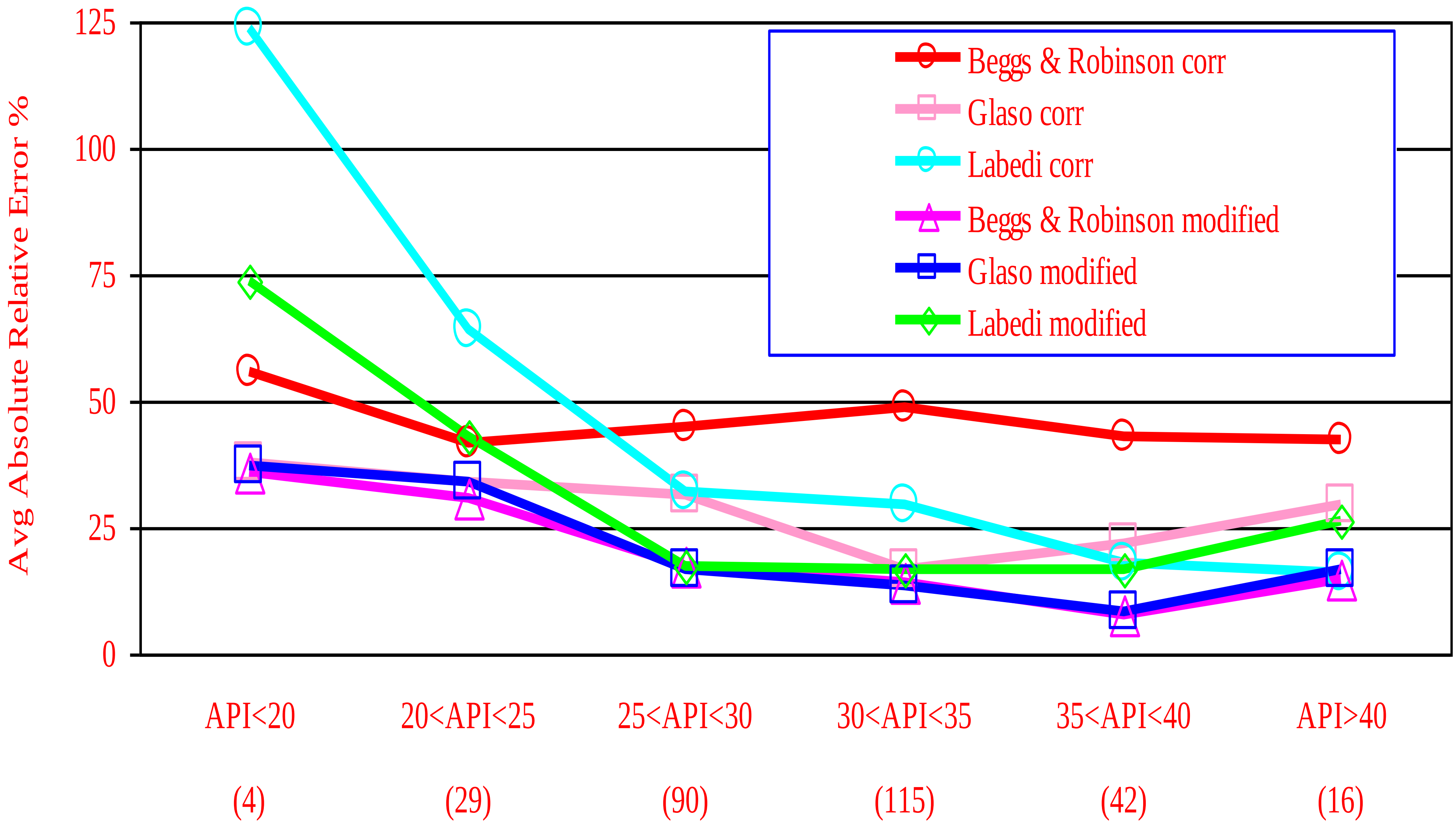
a_1	=	21.23904
a_2	=	-4.7013
a_3	=	-0.6739

Statistical accuracy of μ_{od} correlations

	ER	EA	E max	STD	R
Correlation					
Beggs & Robinson (1975)	-23.02	45.87	444.80	64.86	
Glaso (1980)	23.24	24.75	86.44	17.59	
Labedi (1992)	-8.87	32.47	222.83	45.04	
Modified Correlation					
Beggs & Robinson (1975)	-1.48	16.14	83.63	22.25	0.7411
Glaso (1980)	-2.64	16.06	92.62	22.32	0.7623
Labedi (1992)	-4.18	20.68	128.70	28.67	0.7125

Absolute error of μ_{od} correlations

Absolute error versus API gravity



Interfacial tension – pure substance

The force exerted on the boundary layer between a liquid phase and a vapor phase per unit length

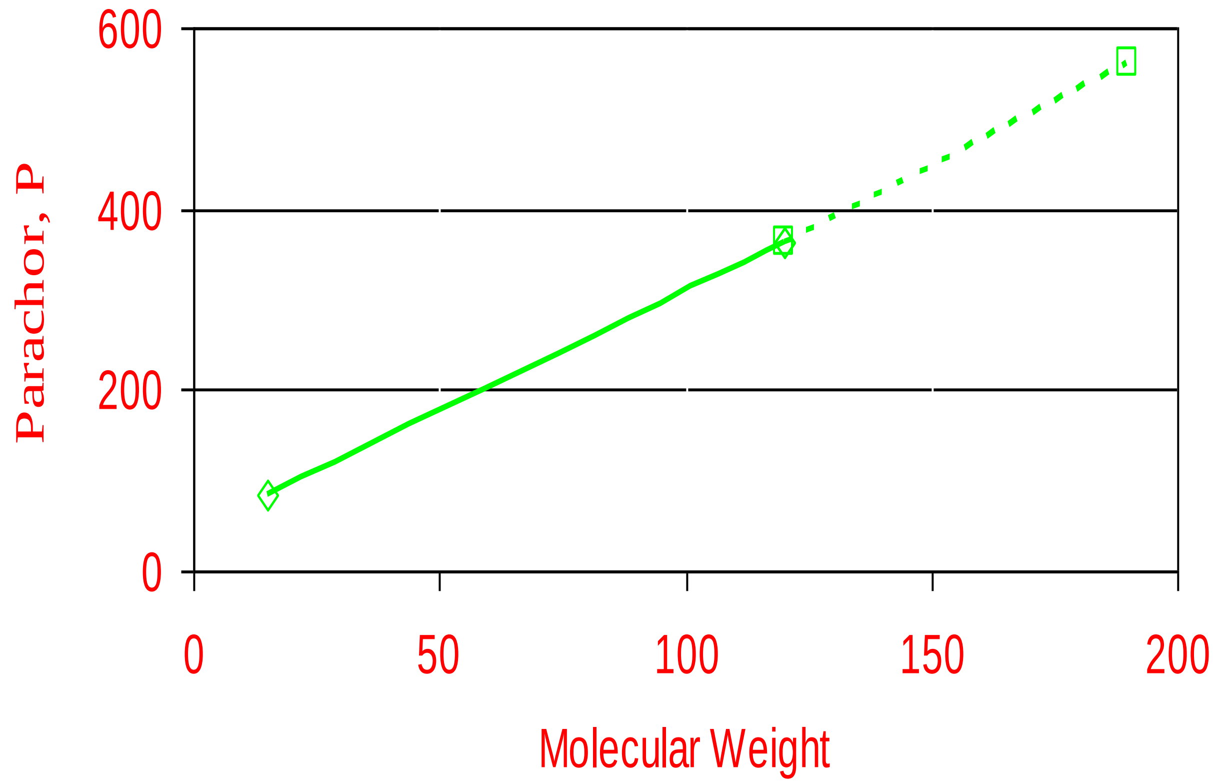
Sugden (1924)

$$\sigma = \left[\frac{P_{ch}(\rho_L - \rho_V)}{M} \right]^4$$

σ = Surface tension for pure substances
P_{ch} = Parachor
ρ_L = Density of the liquid
ρ_V = Density of the vapor
M = Molecular mass

Interfacial tension – parachors

- Parachor is a function expressing the relationship between the surface tension, density, and molecular mass.



Parachors for computing interfacial tension of normal paraffin hydrocarbons

Interfacial tension–hydrocarbon mixture

- **Katz et al. (1943)**

$$\sigma^{1/4} = \sum_{i=1}^{n} [(P_{ch})_i (Ax_i - By_i)]$$

$$A = \frac{\rho_o}{62.4 M_L} \qquad B = \frac{\rho_g}{62.4 M_g}$$

ρ_o = density of oil phase, lb/ft^3

M_L = apparent molecular mass of oil phase

ρ_g = density of gas phase, lb/ft^3

M_g = apparent molecular mass of gas phase

x_i = mole fraction of component i in oil phase

y_i = mole fraction of component i in gas phase

n = total number of component in the system

References

1. Standing, M.B.: "A Pressure-Volume-Temperature Correlation for Mixtures of California Oils and Gases," *Drill. & Prod. Pract*, API (1947), pp 275-287.
2. Vasquez, M.E. and Beggs, H.D.: "Correlations for Fluid Physical Property Prediction," *JPT (*June 1980) 968-970.
3. Al-Marhoun, M.A.: "PVT Correlations for Middle East Crude Oils," *JPT* (May 1988) 650-666.
4. Al-Marhoun, M.A.: "New Correlation for Formation Volume Factor of Oil and Gas Mixtures," *JCPT* (March 1992) 22-26.
5. Glaso, O.: "Generalized Pressure-Volume Temperature Correlations," *JPT* (May 1980), 785-795.
6. Petrosky, G.E. Jr. and Farshad, F.F.: "Pressure-Volume-Temperature Correlations for Gulf of Mexico," paper SPE 26644, presented at the 1993 SPE Annual Technical Conference and Exhibition, Houston, Oct. 3-6.
7. Al-Marhoun, M.A.: "The Coefficient of Isothermal Compressibility of Black Oils," paper SPE 81432 presented at the 2003 SPE Middle East Oil Show and Conference, Bahrain, June 9-12.

References

8. Beal, C.: "The Viscosity of Air, Water, Natural Gas, Crude Oil and its Associated Gases at Oil Field Temperature and Pressures," Trans., AIME (1946) 165, pp 94-112.
9. Labedi, R.: "Improved Correlations for Predicting the Viscosity of Light Crudes," *J. Pet. Sce. Eng*. (Aug. 1992) 221-234.
10. Al-Marhoun, M.A.: "Evaluation of empirically derived PVT properties for Middle East crude oils," Journal of Petroleum Science and Engineering, 42 (2004) 209-221.
11. Chew, J. and Connally, C.A. Jr.: "A Viscosity Correlation for Gas-Saturated Crude Oils," Trans., AIME (1959) 216, pp 23-25.
12. Beggs, H.D. and Robinson, J.R.: "Estimating the Viscosity of Crude Oil System," *JPT* (Sept. 1980) 1140-41.
13. McCain. W.D. Jr., Rollins, J.B., and Villena. A.J.: "The Coefficient of Isothermal Compressibility of Black Oils at Pressures below the Bubblepoint," *SPEFE* (Sept. 1988) 659-62; Trans., AIME. 285.
14. Al-Marhoun, M.A.: "The Oil Compressibility below Bubble Point Pressure Revisited – Formulations and Estimations," paper SPE 120047 presented at 16th SPE Middle East Oil Show & Conference, Bahrain, 15 – 18 March 2009.