PETE 310

Lecture 21

Black Oils Correlations

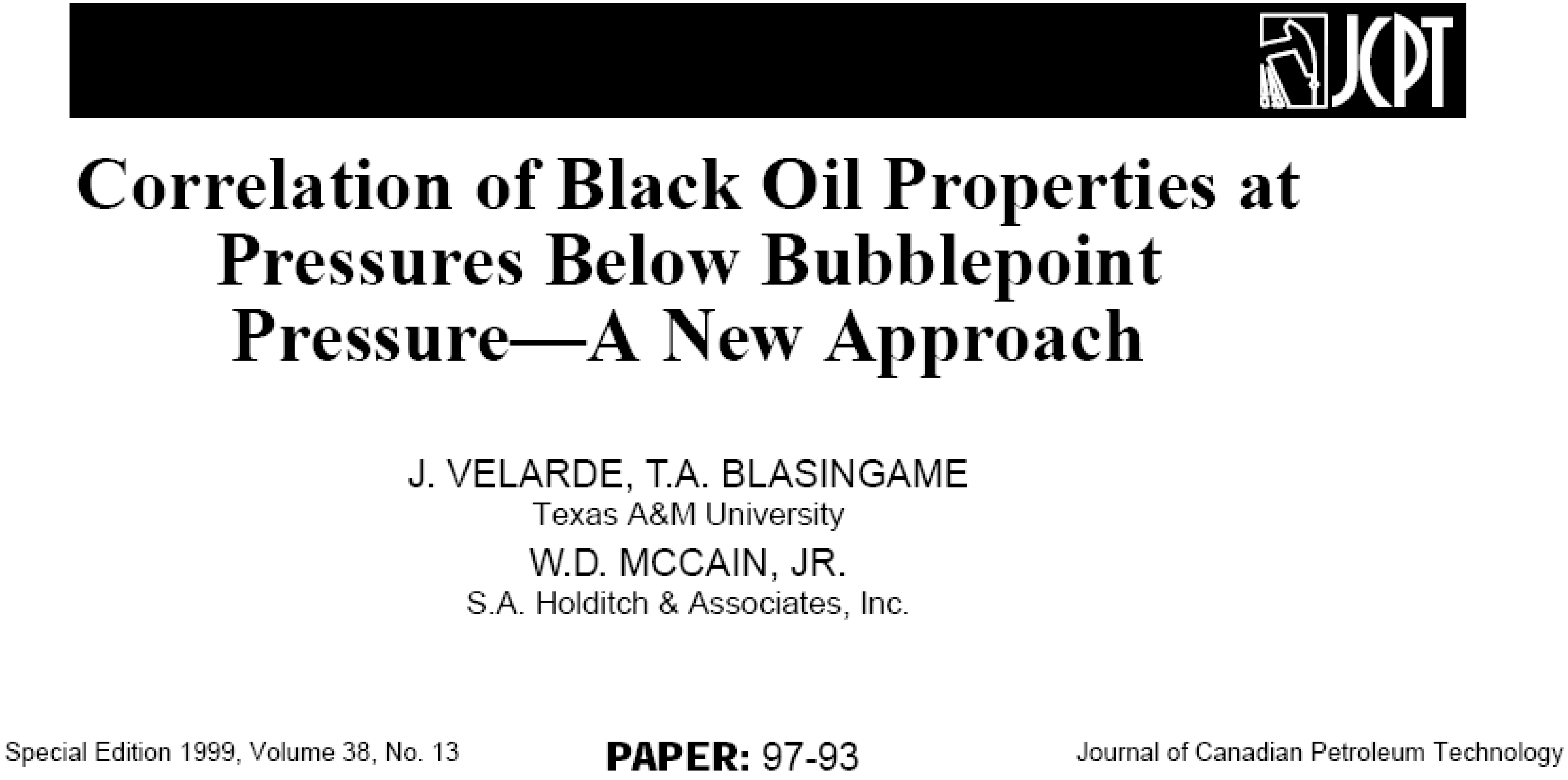
(JCPT paper)

Why Do We Need More Correlations?

- In most correlations material balance connection between B_o, R_s and reservoir densities was not honored
- Experimentally observed curvature shape of R_s was not reproduced
- Bubblepoint pressure needed to be estimated from same correlations (could not impose p_b if this was experimentally known→ inconsistency)

Lecture based on JCPT paper "Correlation of Black Oil Properties at Pressures Below Bubble-Point Pressure – A New Approach" Velarde, Blasingame, McCain

The Source…



Correlation of Black Oil Properties at Pressures Below Bubblepoint Pressure—A New Approach

J. VELARDE, T.A. BLASINGAME
Texas A&M University
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S.A. Holditch & Associates, Inc.

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Correlations Presented

- Solution gas-oil-ratio (R_s)
- Reservoir oil density below the bubble point
- Bubblepoint pressure (p_b)
- B_o is a Derived property from material balance

$$\boxed{B_o = \frac{\rho_{STO} + 0.01357 \times R_s \gamma_{gs}}{\rho_{OR}}}$$

- more about this later…

Correlations Presented: R_s

- Solution Gas-oil-ratio R_s given:
  - Bubblepoint pressure p_b [=] psig
  - Reservoir temperature T [=] °F
  - Separator gas gravity (γ_{gs})
  - Stock tank oil API gravity (γ_{API} in paper)
- Define reduced variables

$$R_{sr} = \frac{R_s}{R_{sb}} \leq 1 \qquad p_r = \frac{p}{p_b} \leq 1$$

Correlations Presented: R_s

$$R_{sr} = a_1 \times pr^{a_2} + \left(1 - a_1\right) \times pr^{a_3}$$

$$a_1 = A0 \times \gamma_{gs}{}^{A1} \times API^{A2} \times T^{A3} \times p_b{}^{A4}$$

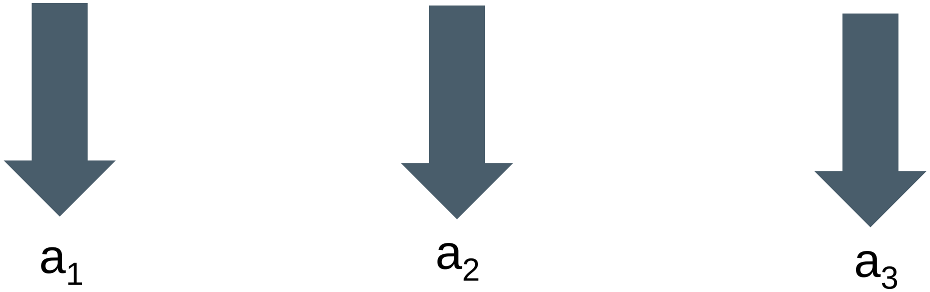
$$a_2 = B0 \times \gamma_{gs}{}^{B1} \times API^{B2} \times T^{B3} \times p_b{}^{B4}$$

$$a_3 = C0 \times \gamma_{gs}{}^{C1} \times API^{C2} \times T^{C3} \times p_b{}^{C4}$$

Correlations Presented: R_s

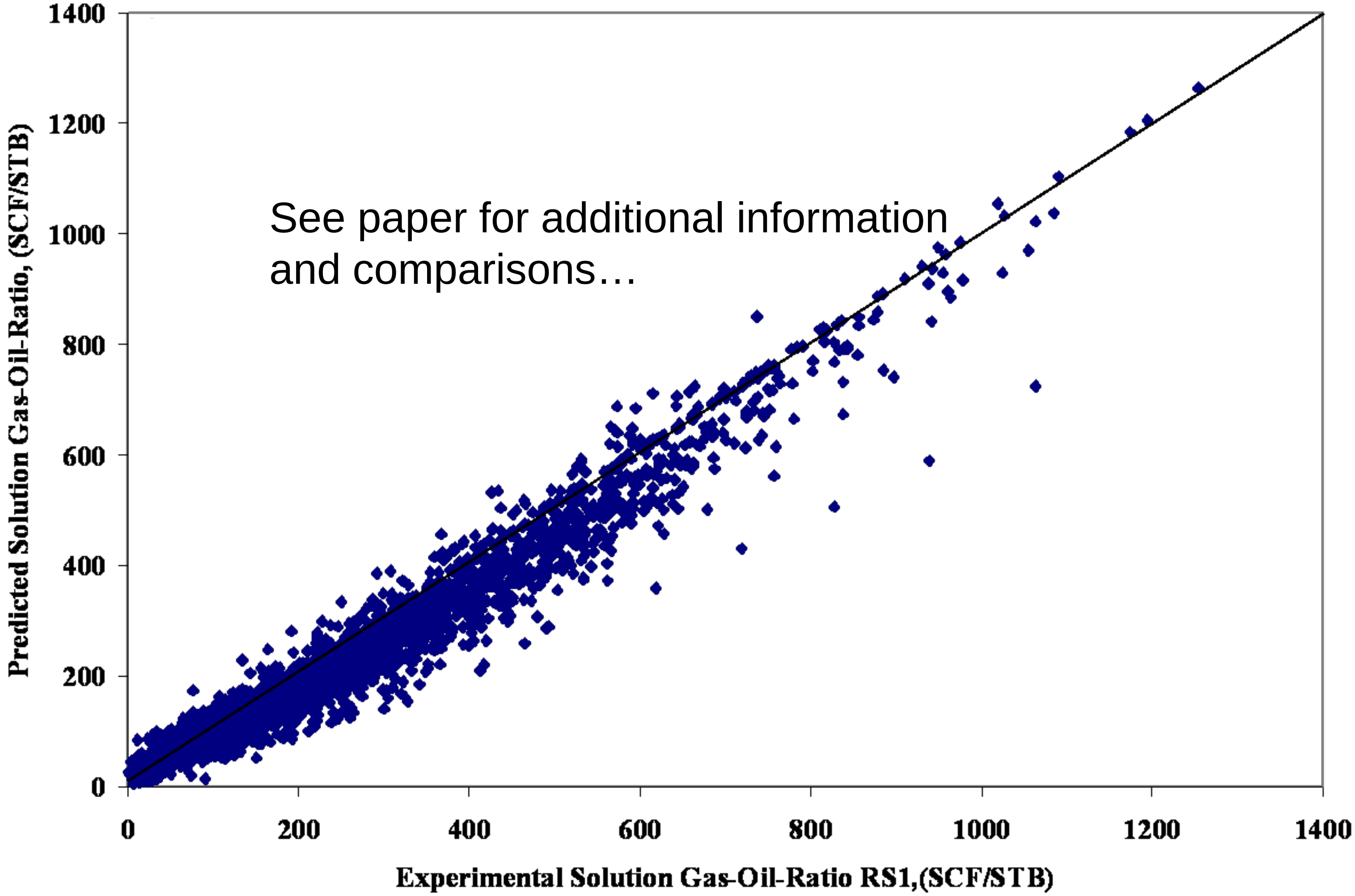
- Coefficients used in equation for R_{sr}

A0=	9.73E-07	B0=	0.022339	C0=	0.725167
A1=	1.672608	B1=	-1.00475	C1=	-1.48548
A2=	0.92987	B2=	0.337711	C2=	-0.164741
A3=	0.247235	B3=	0.132795	C3=	-0.09133
A4=	1.056052	B4=	0.302065	C4=	0.047094



a_1 a_2 a_3

R_s Correlation Performance



See paper for additional information and comparisons…

Correlations Presented: ρ_{oR}

- Given
  - Gravity of separator gas γ_{gs}
  - Gravity of stock tank oil (γ_{STO} , or API gravity)
  - Reservoir temperature
  - Reservoir pressure at or below bubble point pressure
  - Solution gas-oil-ratio (data or correlation)

Correlations Presented: ρ_{oR}

- Iterative stage wise procedure:
  - 1. Guess “pseudo” oil density at standard conditions from a simple equation (Eq.a)
  - 2. Use oil density from (Eq.a) to evaluate “apparent density of gas in solution” as if this was liquid at standard conditions (Eq.b)
  - 3. Reevaluate oil density using (Eq.c) compare with (Eq. a) – repeat steps 2 and 3 until convergence **(EXCEL example will illustrate this)**

Correlations Presented: ρ_{oR}

- Iterative stage wise procedure cont.
  - 4. Converged oil density is at standard conditions adjust first for pressure (Eq.d)
  - 5. Second, adjust for reservoir temperature using corrected oil density from step 4 (Eq. e)
  - 6. If pressure is above p_b use oil compressibility to correct density from step 5.

Equations used for ρ_{oR}

- **Guess oil pseudo density**

$$\rho_{po} = 52.8 - 0.01R_{sb} \qquad \text{(Eq.a)}$$

- **Apparent gas density**

$$\rho_a = -49.8930 + 85.0149 \times \gamma_{gs} - 3.70373 \times \gamma_{gs} \times \rho_{po} + 0.047982 \times \gamma_{gs} \times \rho_{po}^{\ 2} + 2.98914 \times \rho_{po} - 0.035689 \times \rho_{po}^{\ 2}$$

(Eq.b)

Correlations Presented: ρ_{oR}

- **Reevaluate oil pseudo density using recently evaluated apparent gas density**

$$\rho_{po} = \frac{R_s \times \gamma_{gs} + 4600 \times \gamma_{STO}}{73.71 + R_s \times \gamma_{gs} / \rho_a} \qquad \text{(Eq.d)}$$

- **Compare with previous density and iterate till convergence usually 2 to 3 steps are enough**

  - **Recall**

$$\gamma_{STO} = 141.5 / (API + 131.5)$$

Correlations Presented: ρ_{oR}

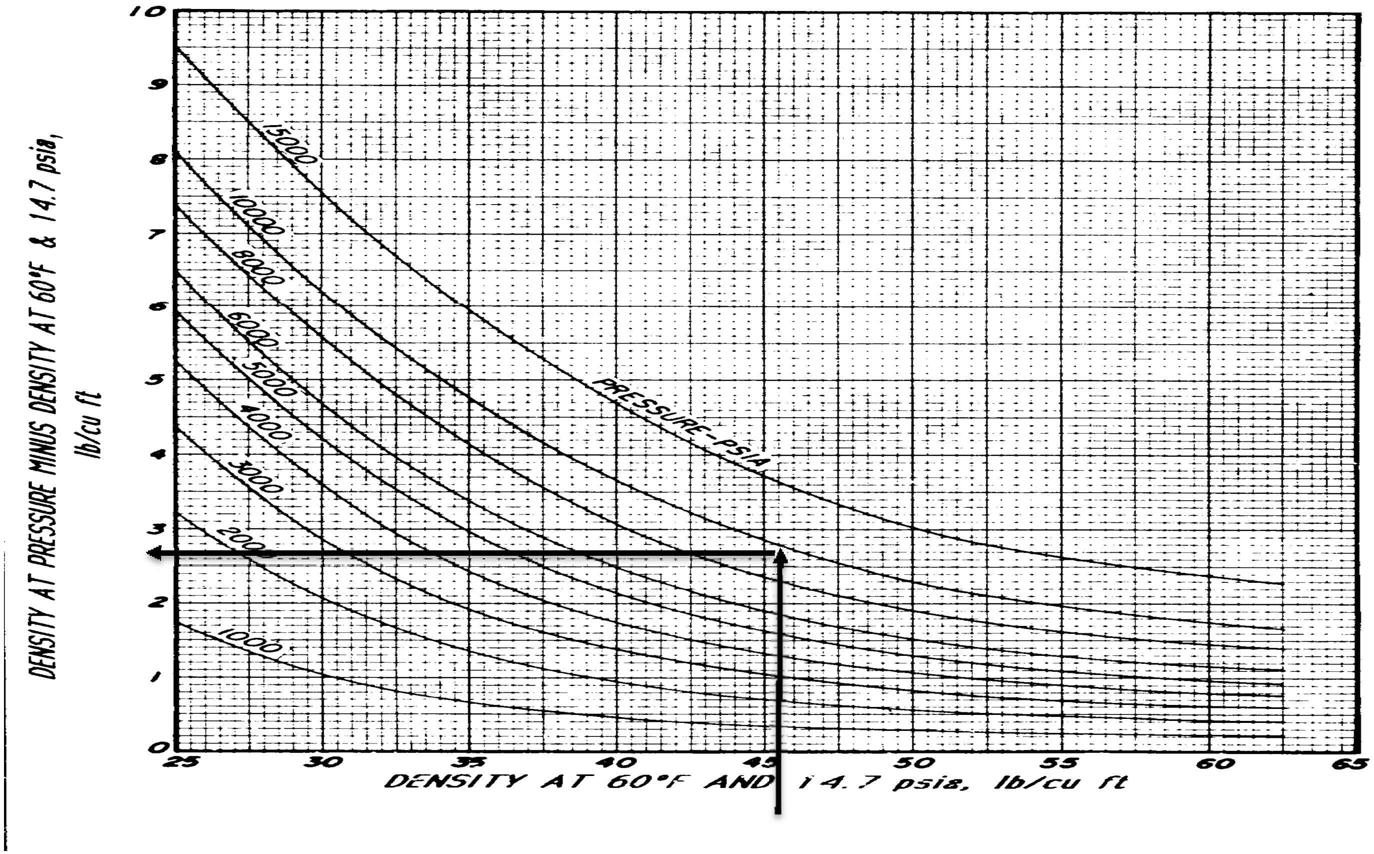
- 1st Pressure correction

$$\rho_o(p,Tsc)=\rho_{po}+\left[0.167+16.181\times\left(10^{-0.0425\times\rho_{po}}\right)\right]\left(\frac{p}{1000}\right)-$$

$$0.01\times\left[0.299+263\times\left(10^{-0.0603\times\rho_{po}}\right)\right]\left(\frac{p}{1000}\right)^2$$

Pressure Correction in graphical form

$$\rho_o(T_{sc},P_R)=\rho_{po}(T_{sc},P_{sc})+\Delta\rho_o(P_R)$$



Correlations Presented: ρ_{oR}

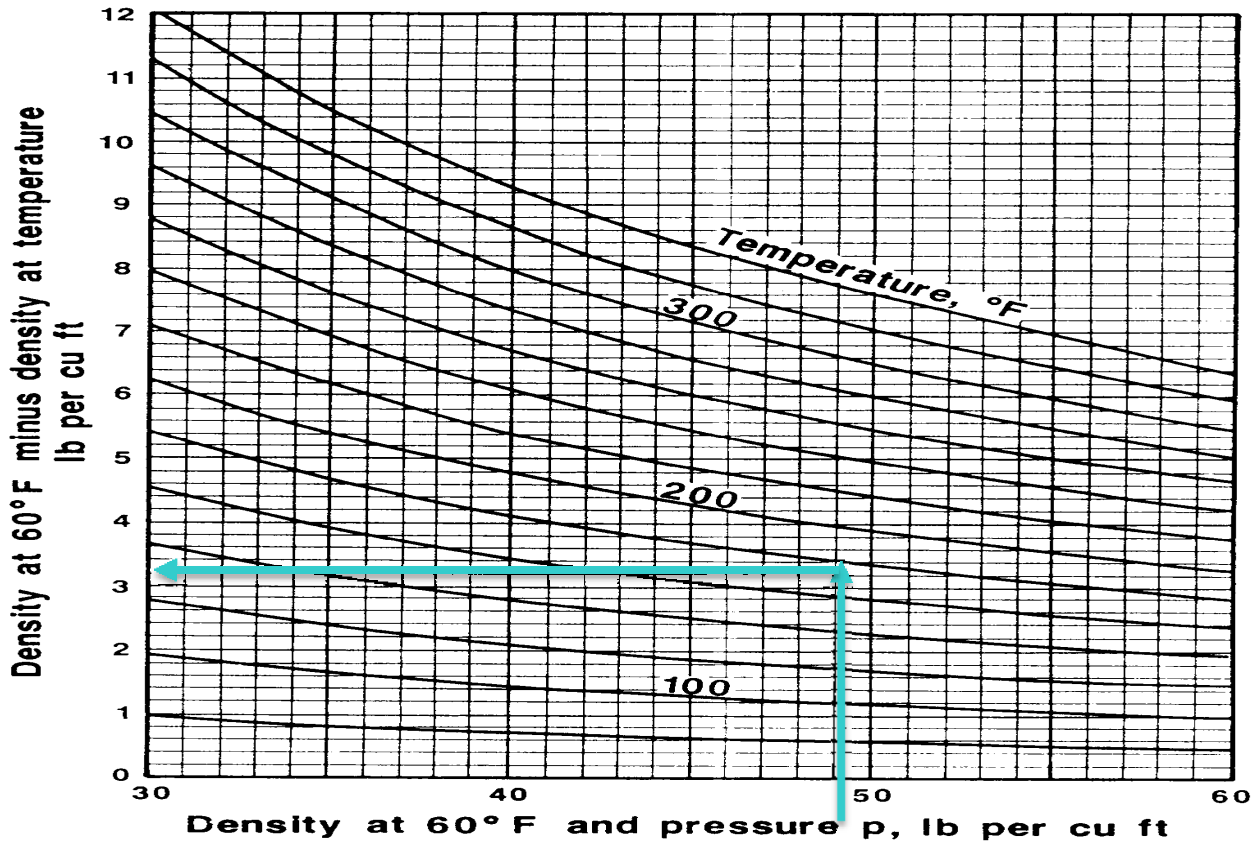
- 2nd Temperature Correction

$$\rho_o(p,T) = \rho_o(p,Tsc) - \left[0.0032 + 1.505 \times \rho_o(p,Tsc)^{-0.951}\right](T-60)^{0.938} - \left[0.0216 - 0.0233 \times \left(10^{-0.0161 \times \rho_o(p,Ts)}\right)\right](T-60)^{0.475}$$

- Note: McCain's book & paper have a sign discrepancy in this formula. Use this formula

Temperature Correction in graphical form

$$\rho(T_R, P_R) = \rho(T_{sc}, P_R) - \Delta\rho(T_R)$$



Correlations Presented: Bubblepoint pressure

- Requires API, γ_{gs}, R_{sb}, and T

$$p_b = 1091.47\left[R_{sb}^{\;0.081465}\gamma_{gs}^{\;-0.161488}10^{X} - 0.740152\right]^{5.354891}$$

  - With

$$X = 0.013098 \times T^{0.282372} - 8.2 \times 10^{-6} API^{2.176124}$$

- Compare p_b from this equation vs. obtained from Fig 11-1 (1947 correlation)

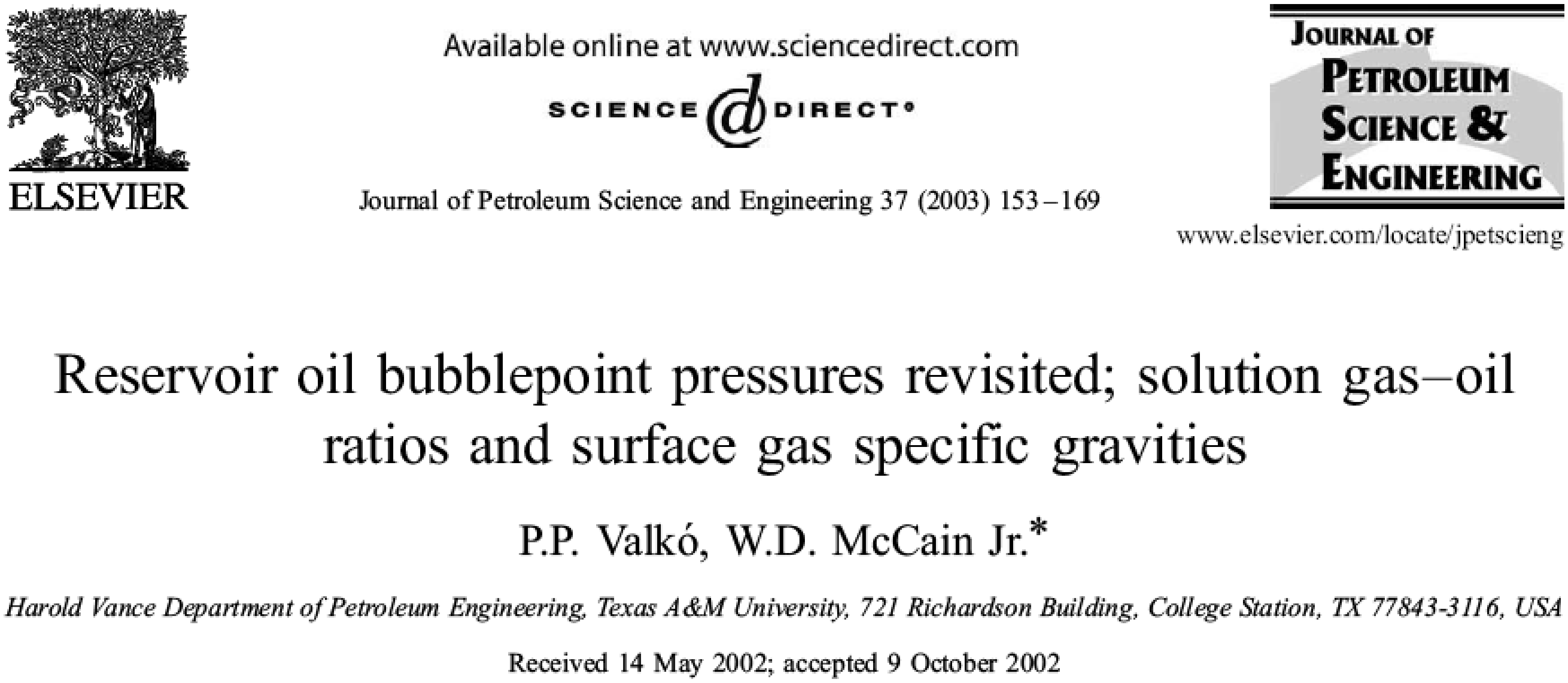
Derived property: B_o

- Strictly using material balance constraints

$$\boxed{B_o = \frac{\rho_{STO} + 0.01357 \times R_s \gamma_{gs}}{\rho_{OR}}}$$

- Same as Eq. 11.5 from your text book … Derive it!

Newer Article & Correlations



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Reservoir oil bubblepoint pressures revisited; solution gas–oil ratios and surface gas specific gravities

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General Advise

- As number of observations / data increase correlations may improve
- Improvement (sometimes) are at the expense of more coefficients
- Be aware of physics, do not fit ‘errors’
- Check boundaries

Judging New Correlations

- **Look at ranges of applicability**

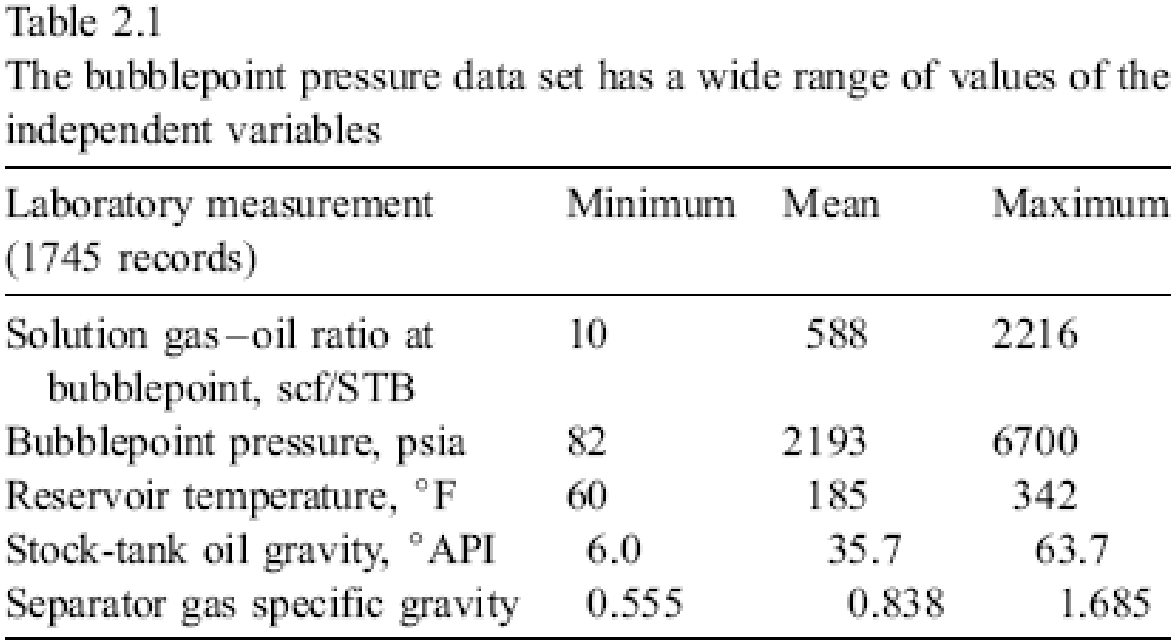


Table 2.1
The bubblepoint pressure data set has a wide range of values of the independent variables

Laboratory measurement (1745 records)	Minimum	Mean	Maximum
Solution gas–oil ratio at bubblepoint, scf/STB	10	588	2216
Bubblepoint pressure, psia	82	2193	6700
Reservoir temperature, °F	60	185	342
Stock-tank oil gravity, °API	6.0	35.7	63.7
Separator gas specific gravity	0.555	0.838	1.685

Judging New Correlations

- Reporting Deviation (or error): relative ARE, absolute (AARE)

$$\mathrm{ARE} = \frac{100}{N}\sum_{i=1}^{N}\frac{y_{\mathrm{calculated}} - y_{\mathrm{measured}}}{y_{\mathrm{measured}}} \qquad (1-2)$$

$$\mathrm{AARE} = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{y_{\mathrm{calculated}} - y_{\mathrm{measured}}}{y_{\mathrm{measured}}}\right| \qquad (1-3)$$

Judging ….

- Reporting Deviation (or error): relative ARE, absolute (AARE)

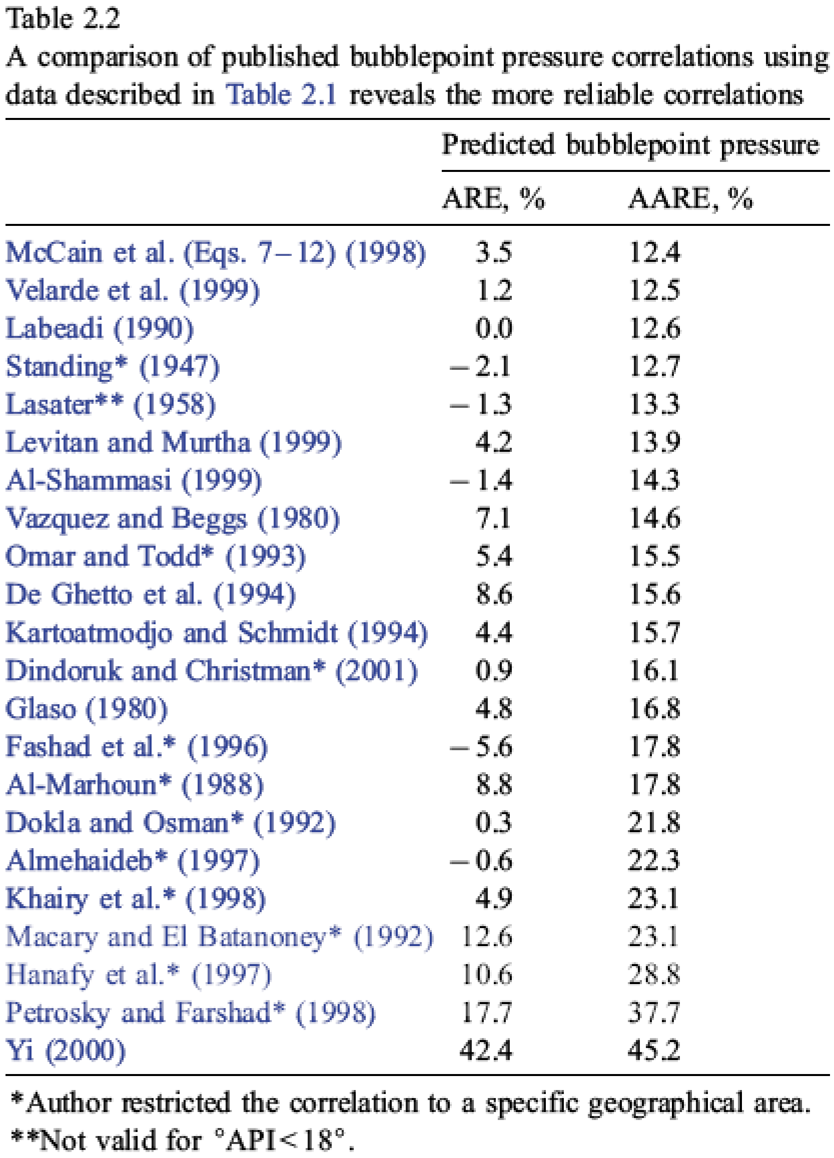


Table 2.2

A comparison of published bubblepoint pressure correlations using data described in Table 2.1 reveals the more reliable correlations

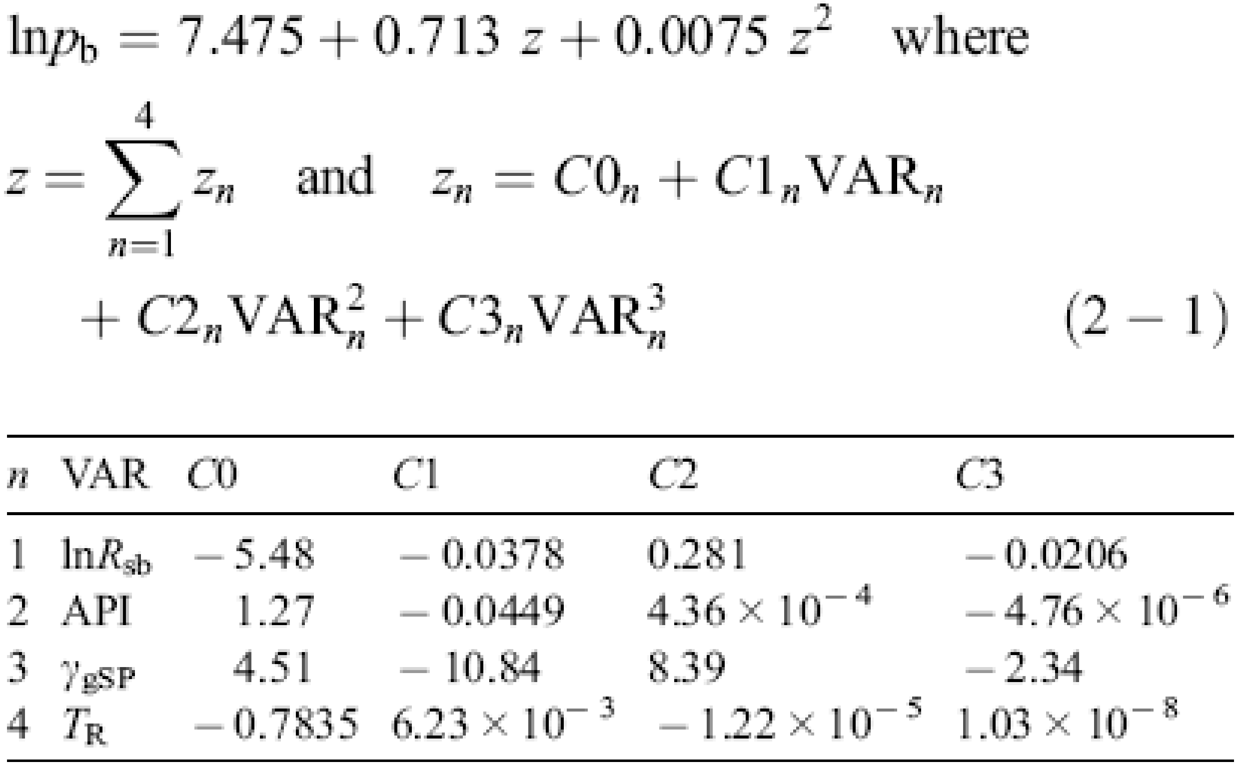
	Predicted bubblepoint pressure	
	ARE, %	AARE, %
McCain et al. (Eqs. 7–12) (1998)	3.5	12.4
Velarde et al. (1999)	1.2	12.5
Labeadi (1990)	0.0	12.6
Standing* (1947)	–2.1	12.7
Lasater** (1958)	–1.3	13.3
Levitan and Murtha (1999)	4.2	13.9
Al-Shammasi (1999)	–1.4	14.3
Vazquez and Beggs (1980)	7.1	14.6
Omar and Todd* (1993)	5.4	15.5
De Ghetto et al. (1994)	8.6	15.6
Kartoatmodjo and Schmidt (1994)	4.4	15.7
Dindoruk and Christman* (2001)	0.9	16.1
Glaso (1980)	4.8	16.8
Fashad et al.* (1996)	–5.6	17.8
Al-Marhoun* (1988)	8.8	17.8
Dokla and Osman* (1992)	0.3	21.8
Almehaideb* (1997)	–0.6	22.3
Khairy et al.* (1998)	4.9	23.1
Macary and El Batanoney* (1992)	12.6	23.1
Hanafy et al.* (1997)	10.6	28.8
Petrosky and Farshad* (1998)	17.7	37.7
Yi (2000)	42.4	45.2

*Author restricted the correlation to a specific geographical area.

**Not valid for °API < 18°.

Judging New Correlations

- **Easy to implement…**



$$\ln p_b = 7.475 + 0.713\ z + 0.0075\ z^2 \quad \text{where}$$

$$z = \sum_{n=1}^{4} z_n \quad \text{and} \quad z_n = C0_n + C1_n \mathrm{VAR}_n + C2_n \mathrm{VAR}_n^2 + C3_n \mathrm{VAR}_n^3 \qquad (2-1)$$

n	VAR	$C0$	$C1$	$C2$	$C3$
1	$\ln R_{sb}$	-5.48	-0.0378	0.281	-0.0206
2	API	1.27	-0.0449	4.36×10^{-4}	-4.76×10^{-6}
3	γ_{gSP}	4.51	-10.84	8.39	-2.34
4	T_R	-0.7835	6.23×10^{-3}	-1.22×10^{-5}	1.03×10^{-8}

Which Method to Use?

- HW are to be done using formulae from older paper – NOT the method/charts from the book
- Bonus Problem to the person that provides a bullet proof, user friendly - and with comments - visual basic/ excel code with a comparison of correlations from these two papers

Exercises in Excel file discussed in class…also available from our WEB site