Society of Petroleum Engineers
SPE 2001–2002 Distinguished Lecturer Program
4 July 2002

Reservoir Fluid Properties

State of the Art and Outlook for Future Development

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Outline

- Introduction
- State of the Art
- Determination of PVT properties
- Problems related to PVT
  - Experimentation & Calculations
  - Data smoothing & Correlations
- Artificial neural networks
- PVT Reporting
- Conclusions

Introduction

Fluid Properties

The study of the behavior of vapor and liquid in petroleum reservoirs as a function of pressure, volume, temperature, and composition

Importance of PVT Properties

- Determination of hydrocarbon reserves
- Reservoir and simulation studies
- Design of production facilities

State of the Art

- Graphical correlations are reduced to equations
- Correlations have been improved
- Fluid classification in reservoirs is defined
- Laboratory analyses have been standardized
- Chemical analyses of petroleum are made available
- EOS is utilized to calculate gas-liquid equilibria

Determination of PVT properties

- Laboratory measurements using:
  - Bottom hole sample
  - Recombined surface sample
- Equation of state with appropriate calibrations
- Empirical correlations with appropriate range of application
- Artificial neural networks models

Problems related to experimentation

- Reservoir process presentation
- Physical trends of lab data

Reservoir process presentation

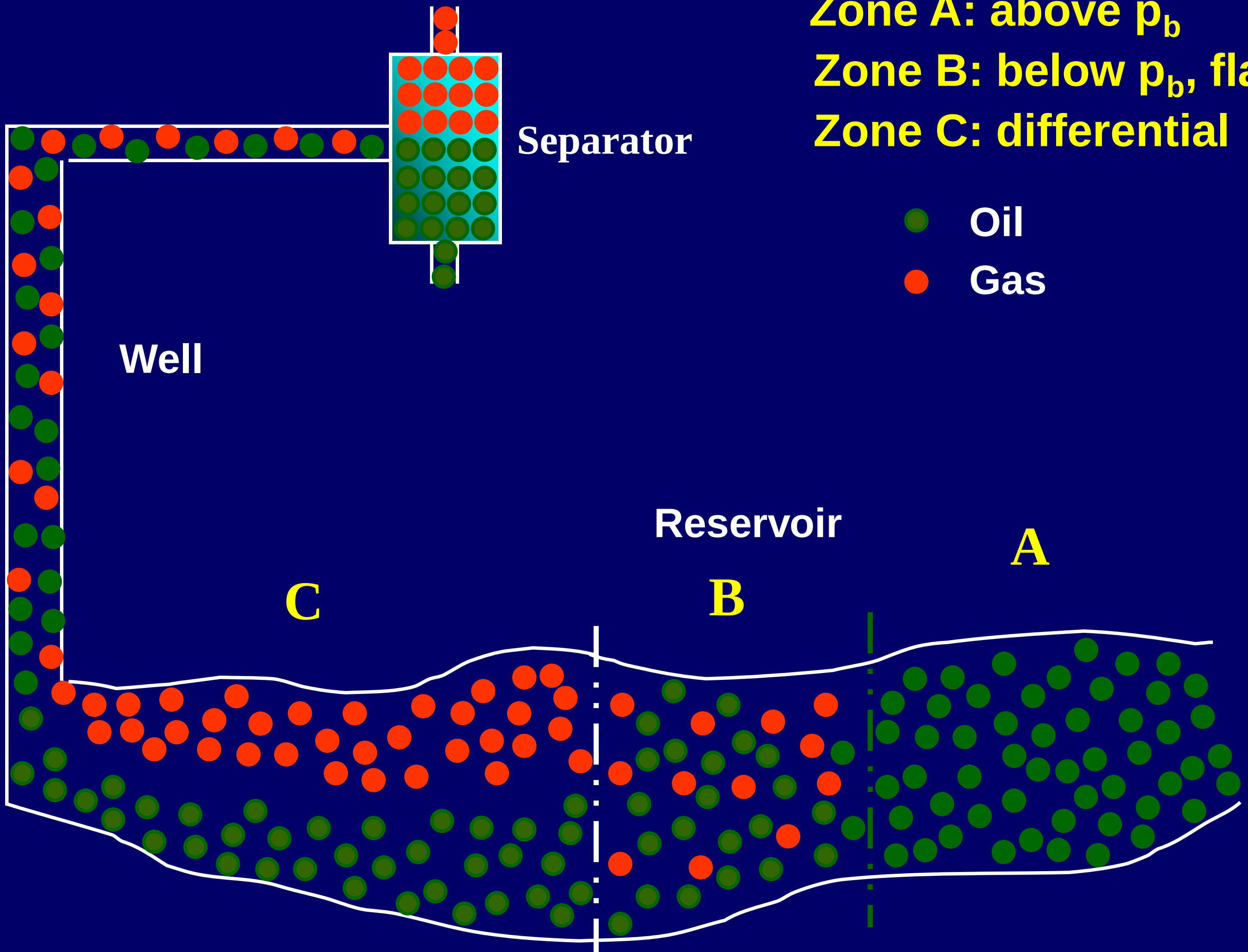
- Lab tests do not duplicate reservoir process
- Petroleum engineers consider liberation process in reservoir approaches differential
- Liberation process around well is considered flash
- Actual process is neither flash nor differential
- A combination test may be closest to the reservoir process

Phase transition in oil reservoir

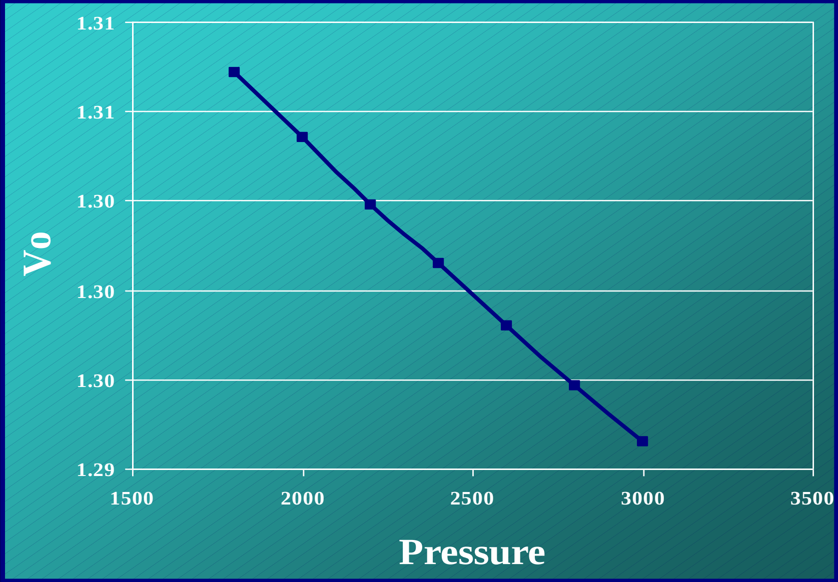
Zone A: above p_b

Zone B: below p_b, flash

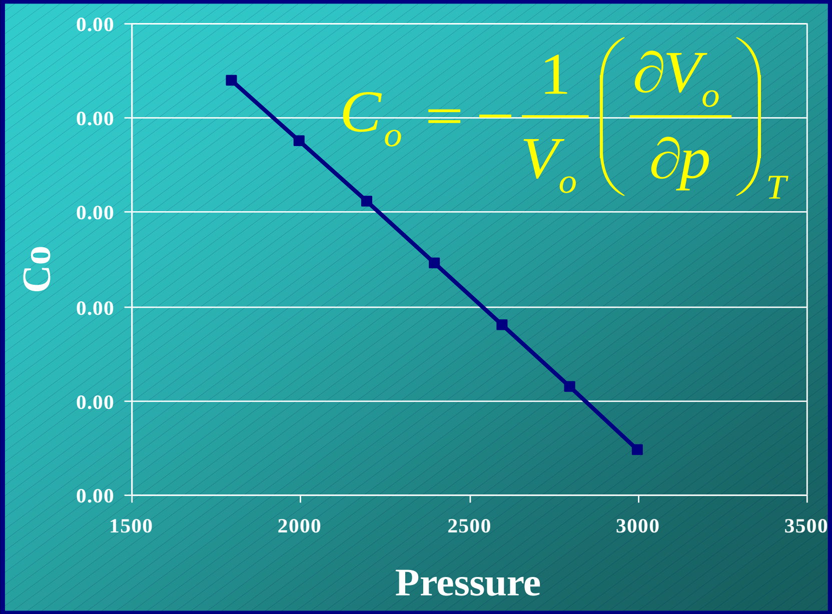
Zone C: differential



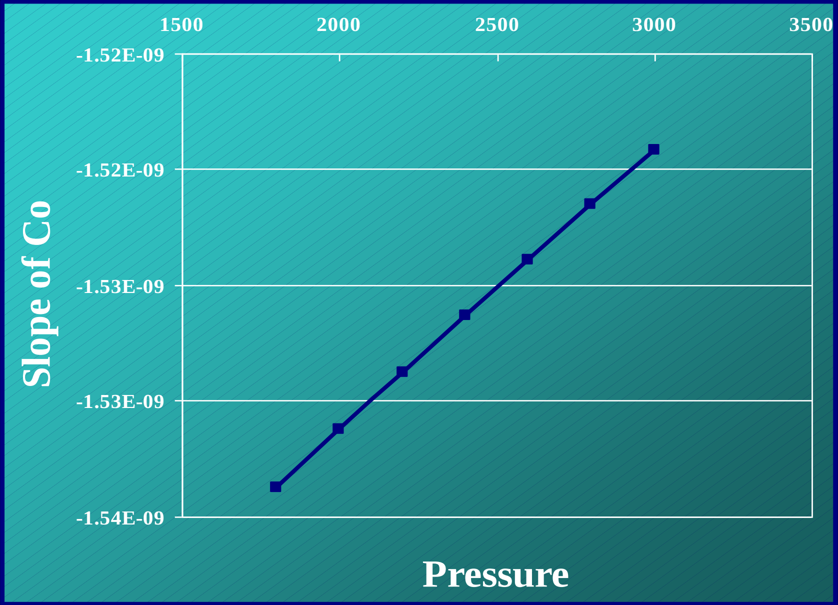
Typical trends of good lab data



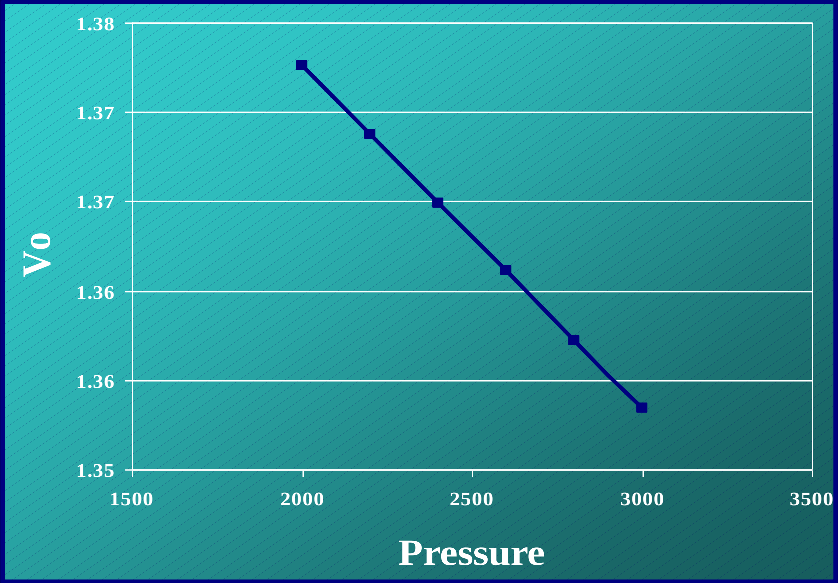
- Good experimental P-V data should follow physical trend.
- Volume decreases with P
- C_o decreases with P
- $-dC_o/dp$ decreases with P



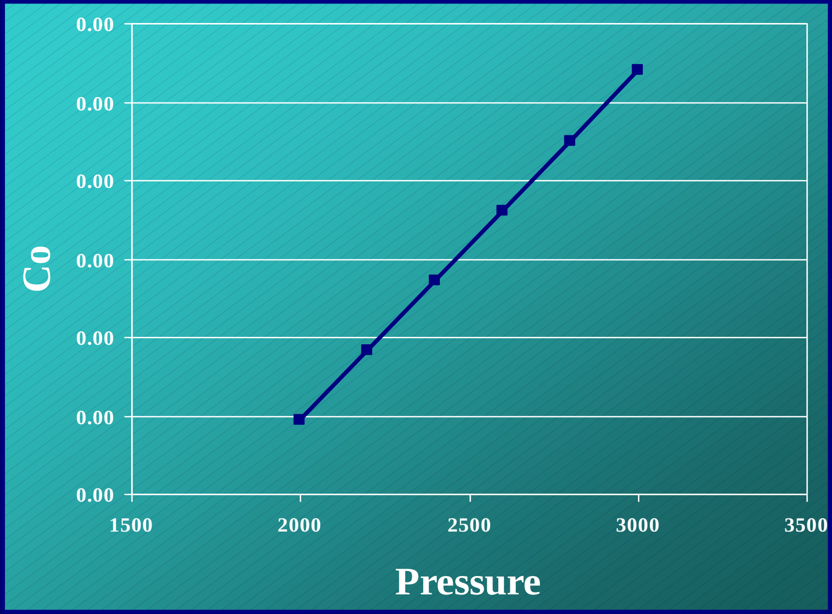
$$C_o = -\frac{1}{V_o}\left(\frac{\partial V_o}{\partial p}\right)_T$$

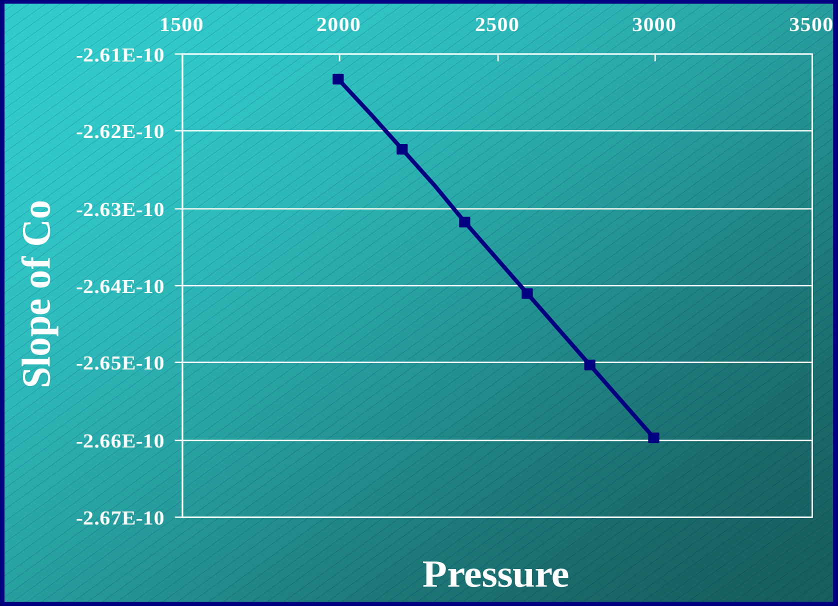


Abnormal C_o trend

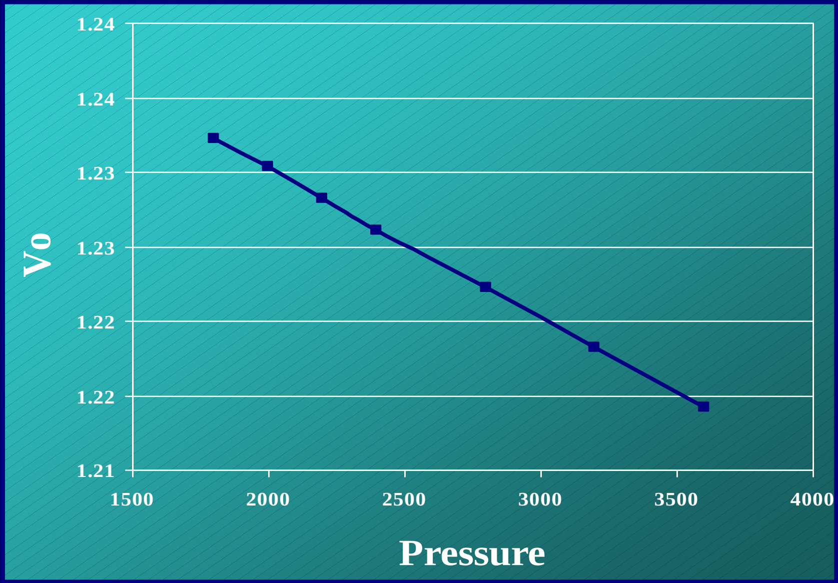


- C_o should decrease with pressure

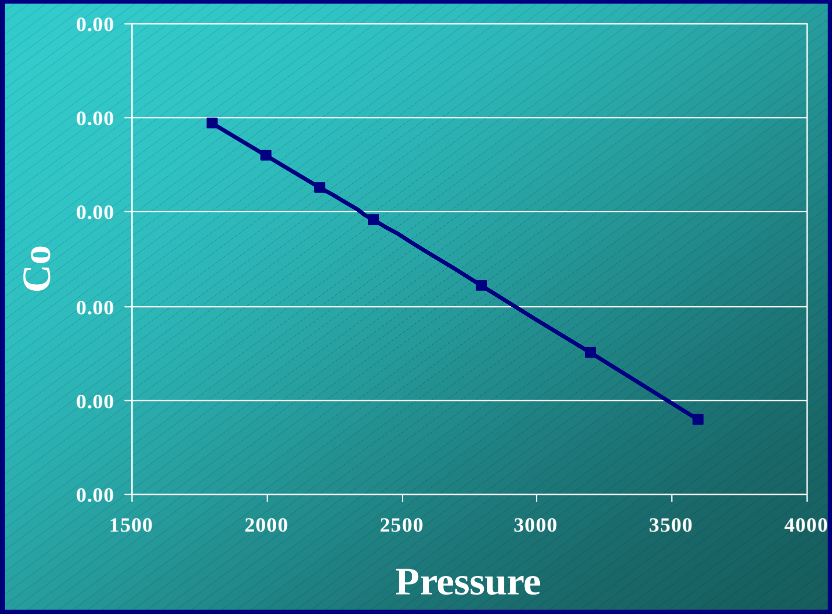


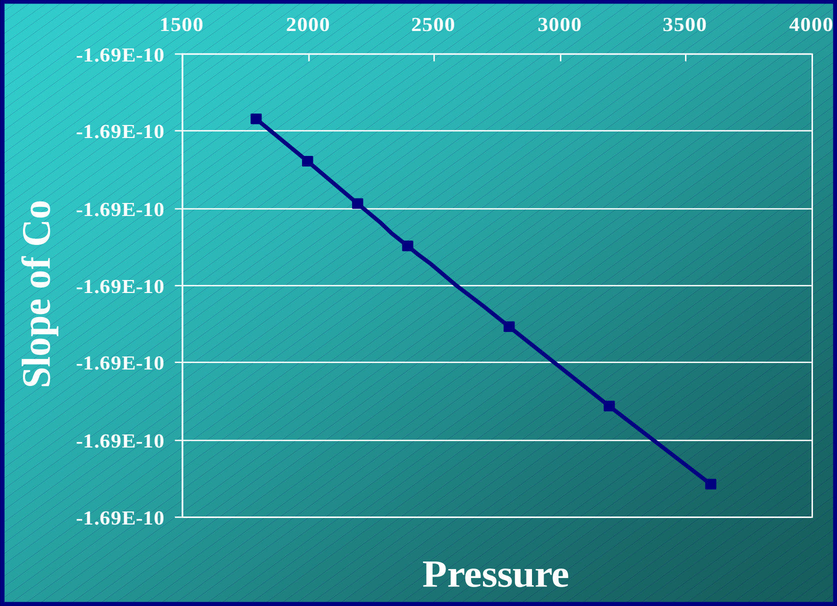


Abnormal C_o derivative trend



- $-dC_o/dp$ should decrease with pressure





Problems related to calculations

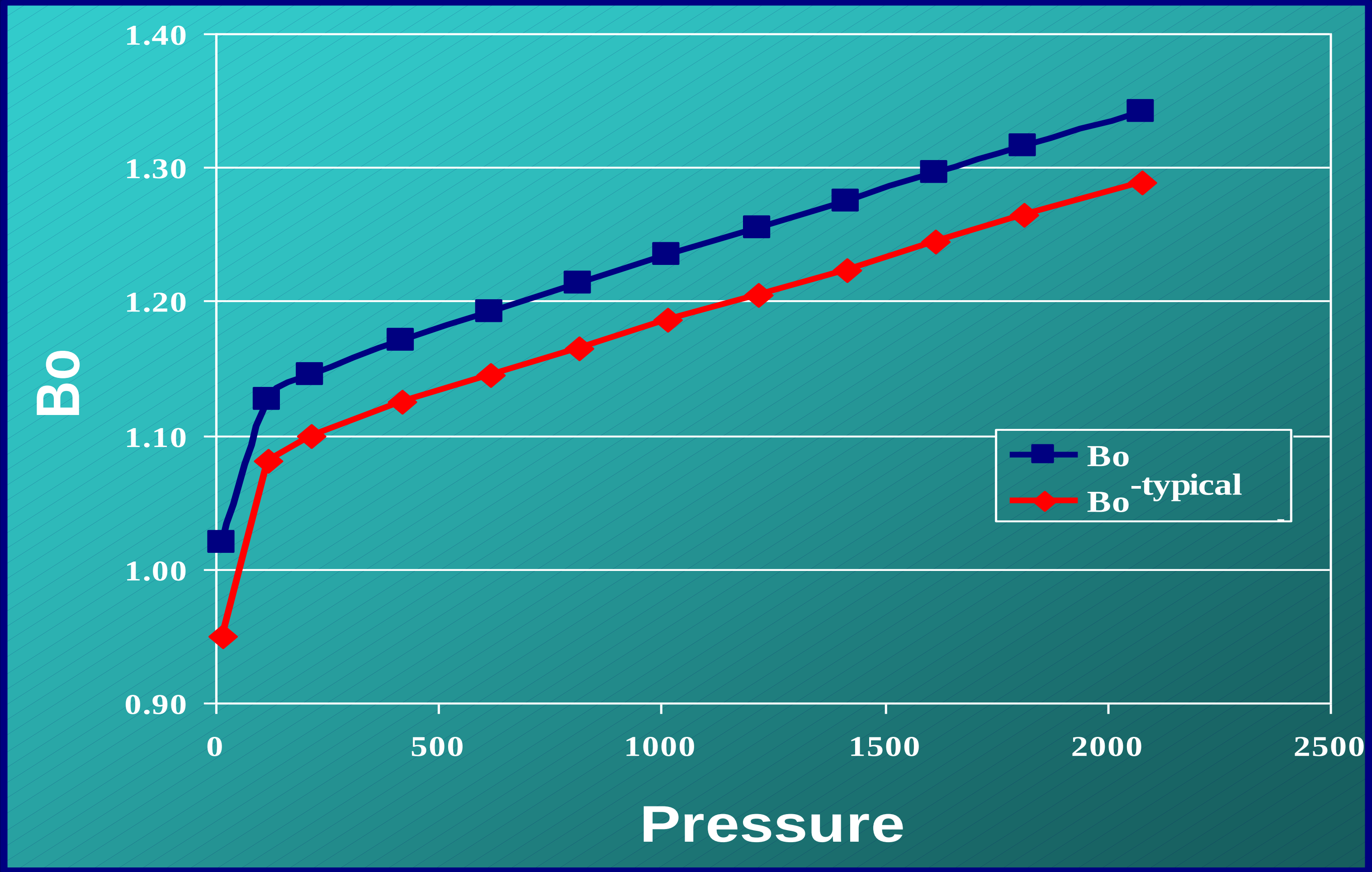
Adjustment of differential data
as an example

Adjustment of differential data to separator conditions -Why?

- R_s and $\mathbf{B_o}$ obtained by differential liberation are not the same as
  R_s and $\mathbf{B_o}$ obtained by flash liberation
- Oil leaving reservoir is flashed to separator, therefore R_s and $\mathbf{B_o}$ should be determined by a flash process
- Flash liberation does not cover whole range of interest, therefore differential data are corrected

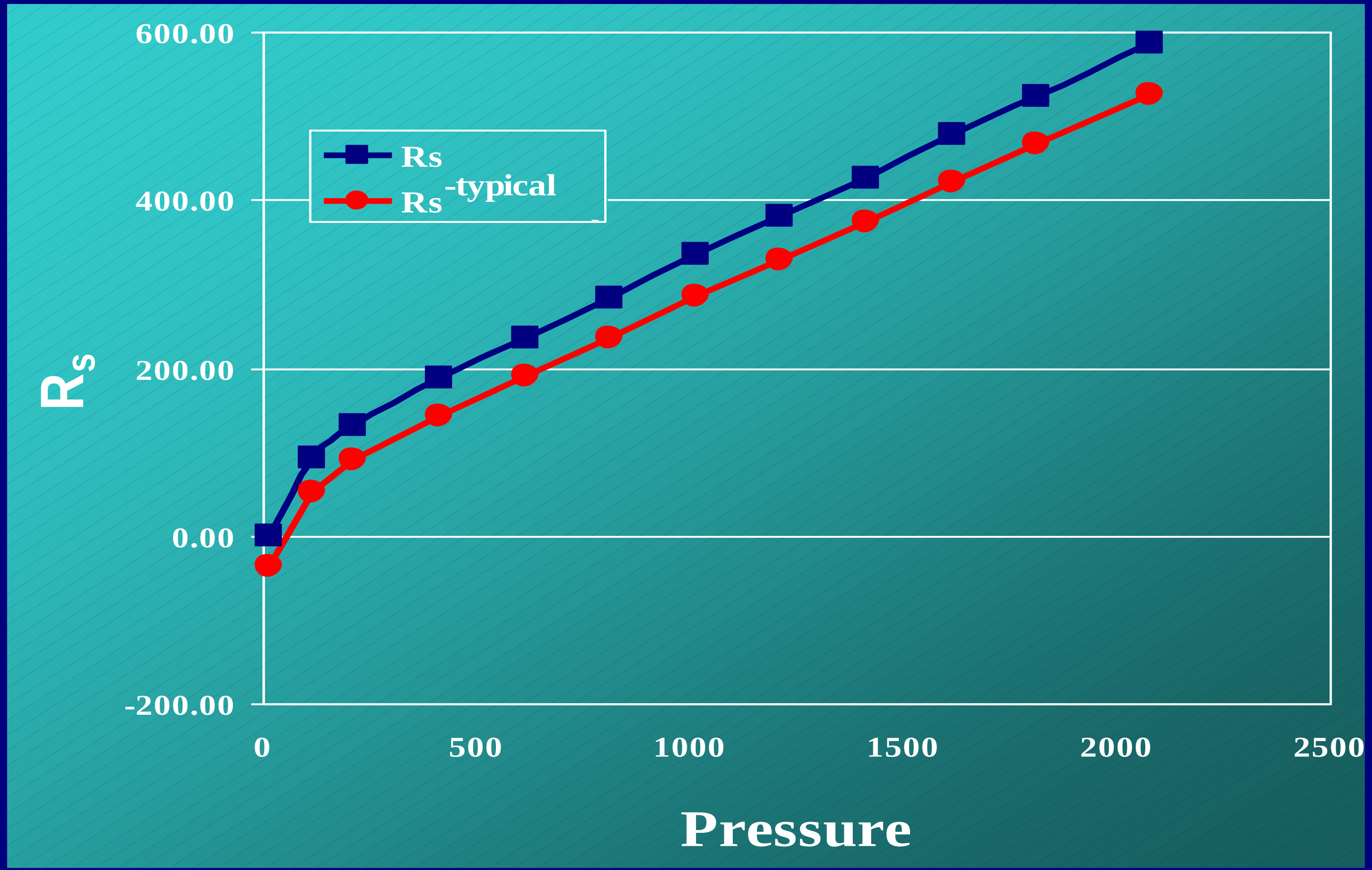
Current adjustment method-Properties

- At lower pressure formation volume factor, **B_o** might read a value less than 1



Current adjustment method-Properties

- At lower pressure, the solution gas-oil ratio, R_s extrapolates to negative values.



Current adjustment method-Properties

- Current adjustment method does not honor density at bubble point under reservoir conditions

- The same crude under the same reservoir conditions, but different densities

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

Property	Adjusted Differential	Flash Liberation
B_{ob}	1.289	1.289
R_s	526	526
γ_g	0.9336	0.8024
γ_o	0.8448	0.8343
γ_{ob}	0.738444	0.7186265

Adjustment methods of oil FVF

- Current Adjustment of B_o

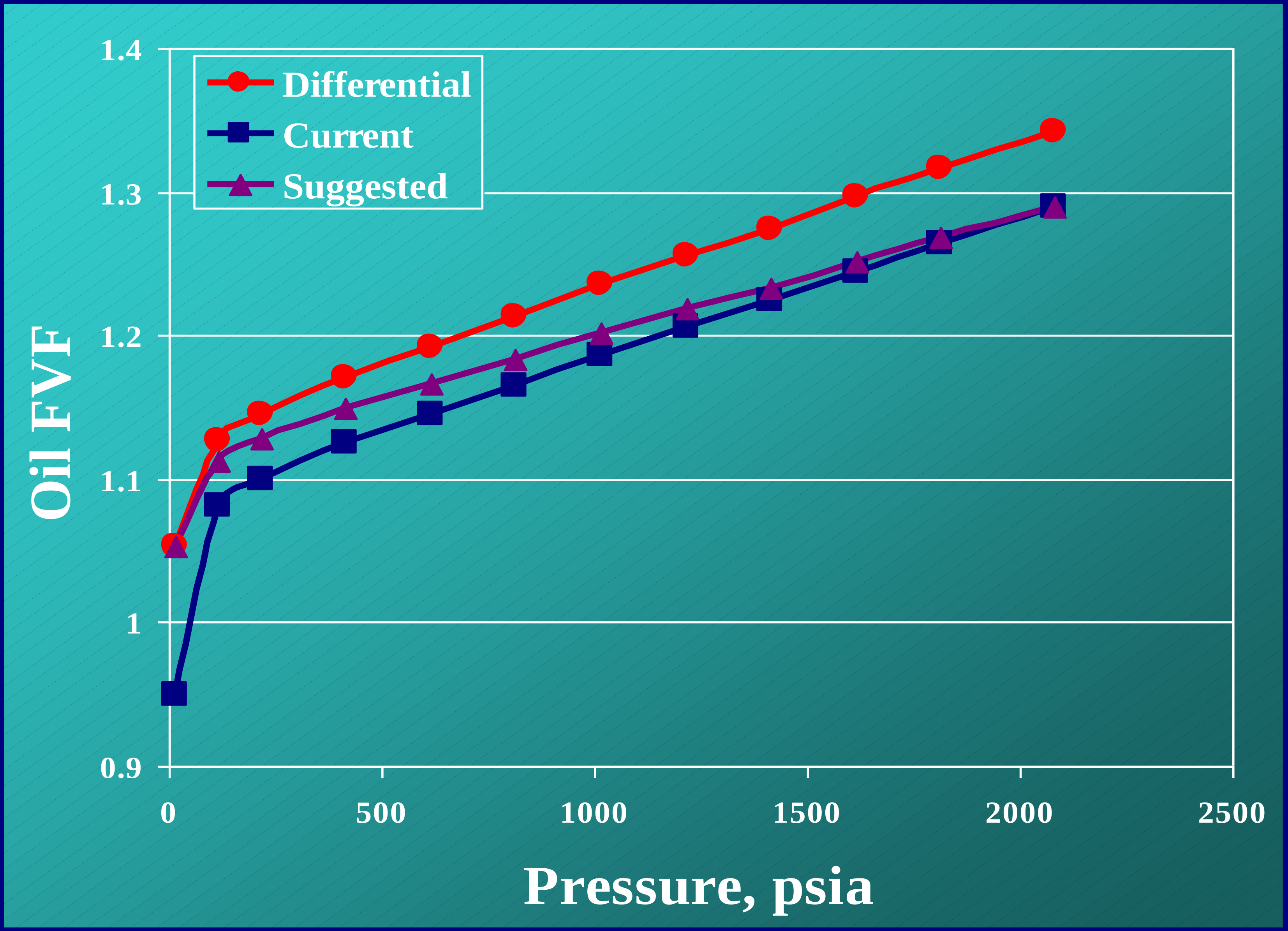
$$B_o = B_{od} \frac{B_{obf}}{B_{obd}}$$

- Suggested Adjustment

$$B_o = B_{obf} + c\left(B_{odn} - B_{obf}\right)$$

$$c = (B_{obd} - B_{od})/(B_{obd} - B_{odn})$$

Oil FVF



1.4
1.3
1.2
1.1
1
0.9
Oil FVF
Differential
Current
Suggested
0
500
1000
1500
2000
2500
Pressure, psia

Adjustment methods of solution GOR

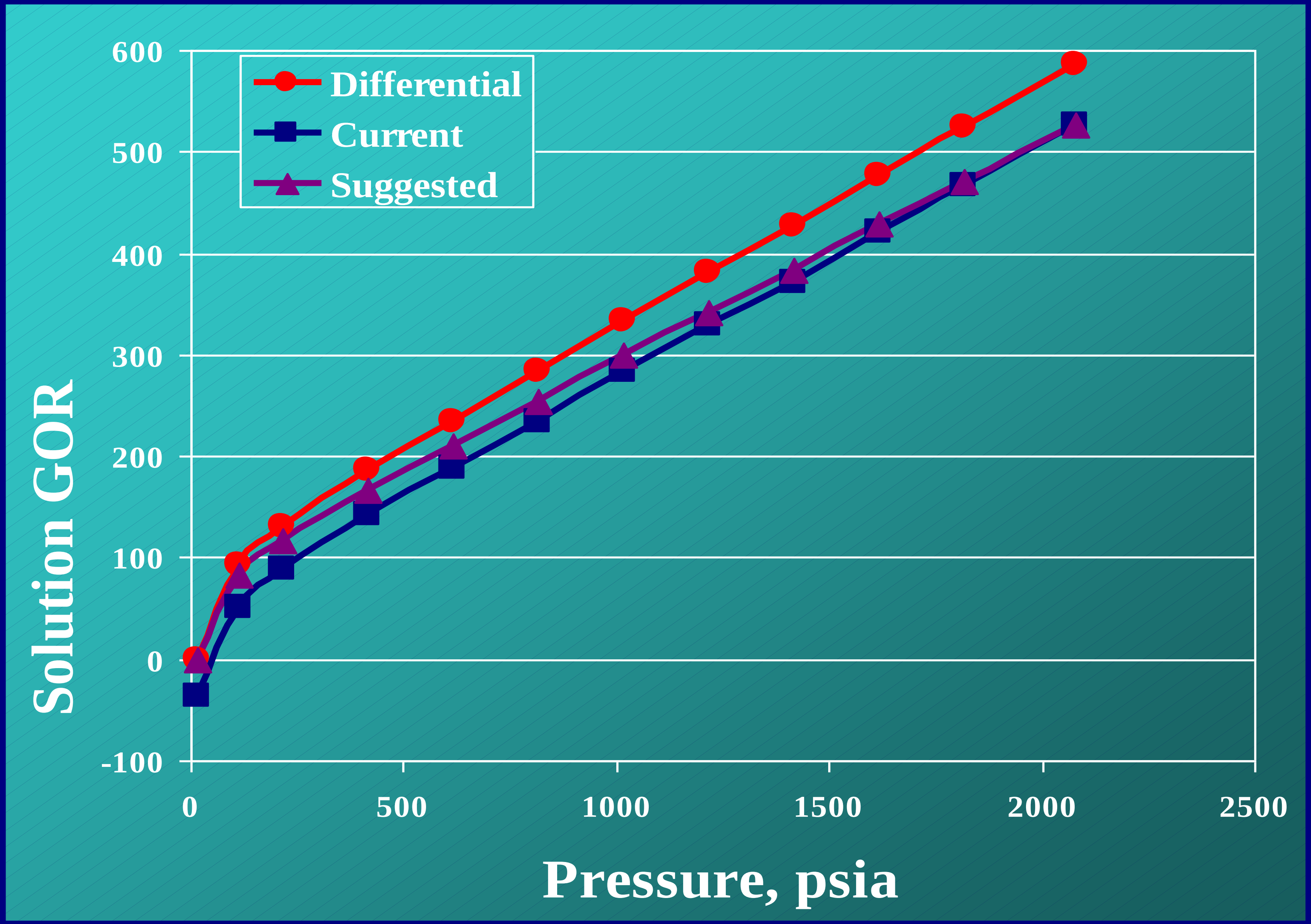
- Current Adjustment of R_s

$$R_s = R_{sbf} - (R_{sbd} - R_{sd})\frac{B_{obf}}{B_{obd}}$$

- Suggested Adjustment

$$R_s = R_{sd}\left(R_{sbf} / R_{sbd}\right)$$

Solution GOR



Adjustment methods of gas relative density

- Current Adjustment of γ_g

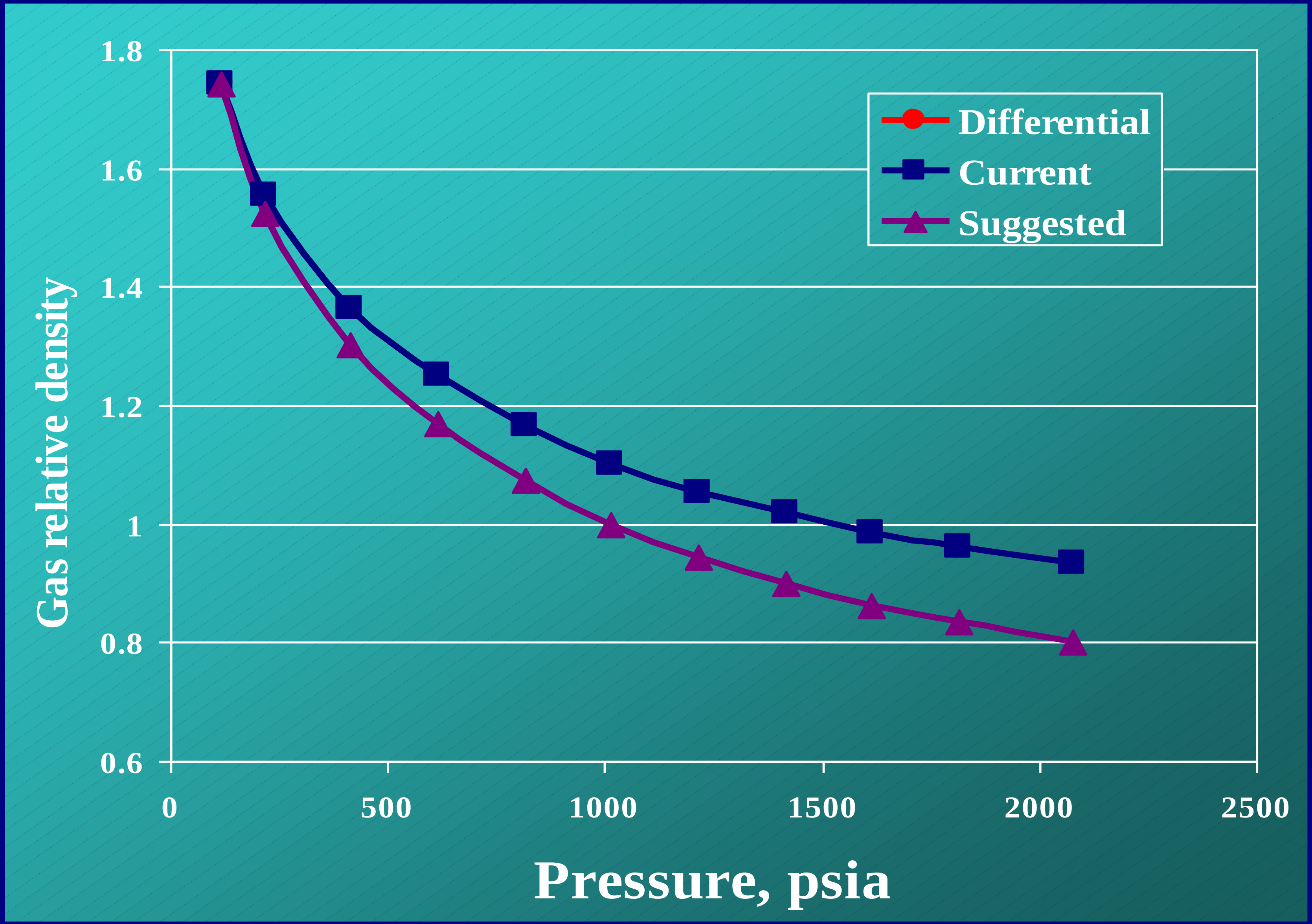
$$\gamma_g = \gamma_{gd}$$

- Suggested Adjustment

$$\gamma_g = \gamma_{gf} + d(\gamma_{gd_{n-1}} - \gamma_{gf})$$

$$d = (\gamma_{gd_1} - \gamma_{gd})/(\gamma_{gd_1} - \gamma_{gd_{n-1}})$$

Gas relative density



Adjustment methods of oil relative density

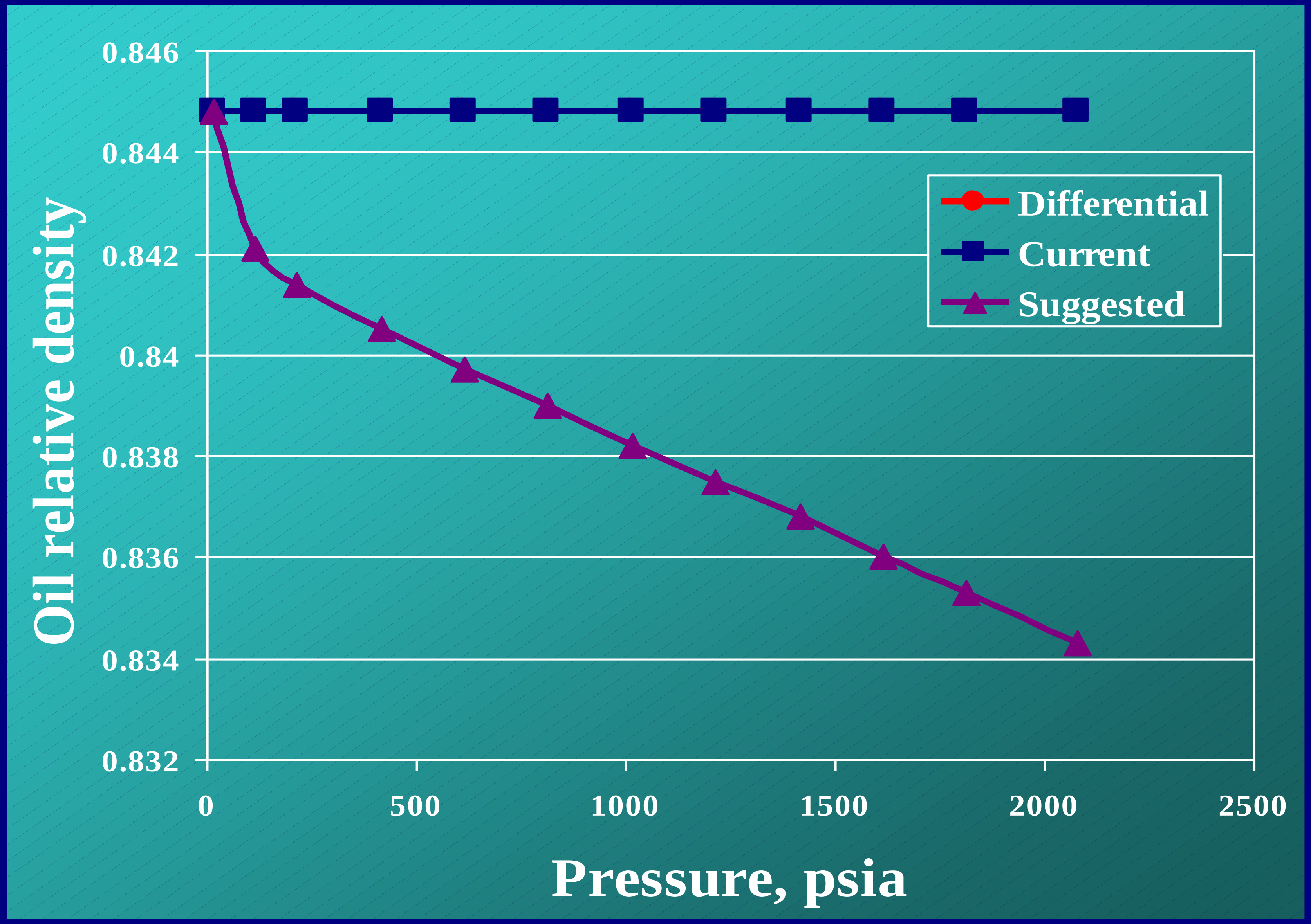
- Current Adjustment of γ_o

$$\gamma_o = \gamma_{od}$$

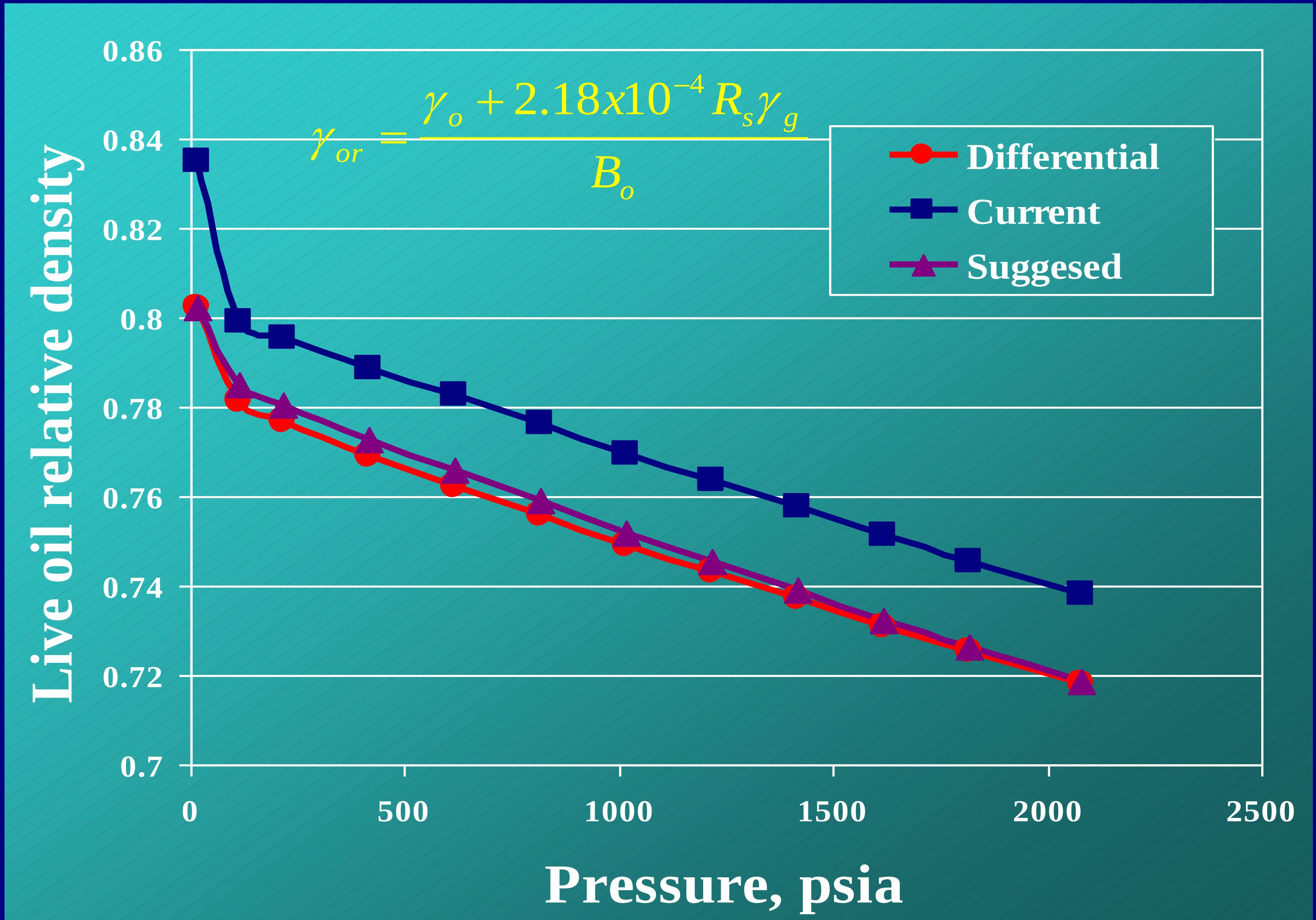
- Suggested Adjustment

$$\gamma_o = \gamma_{of} + c(\gamma_{od} - \gamma_{of})$$

Oil relative density



Live oil relative density



Problems related to Smoothing experimental data

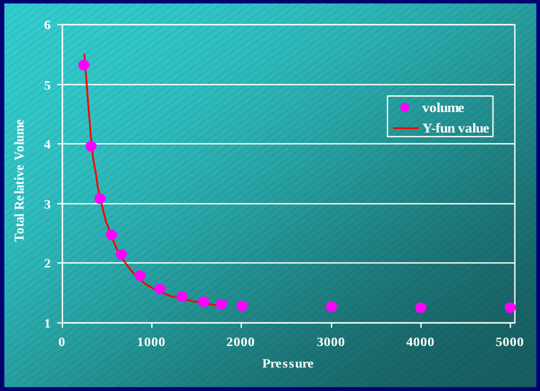
Smoothing relative total volume data
as an example

Smoothing relative total volume data

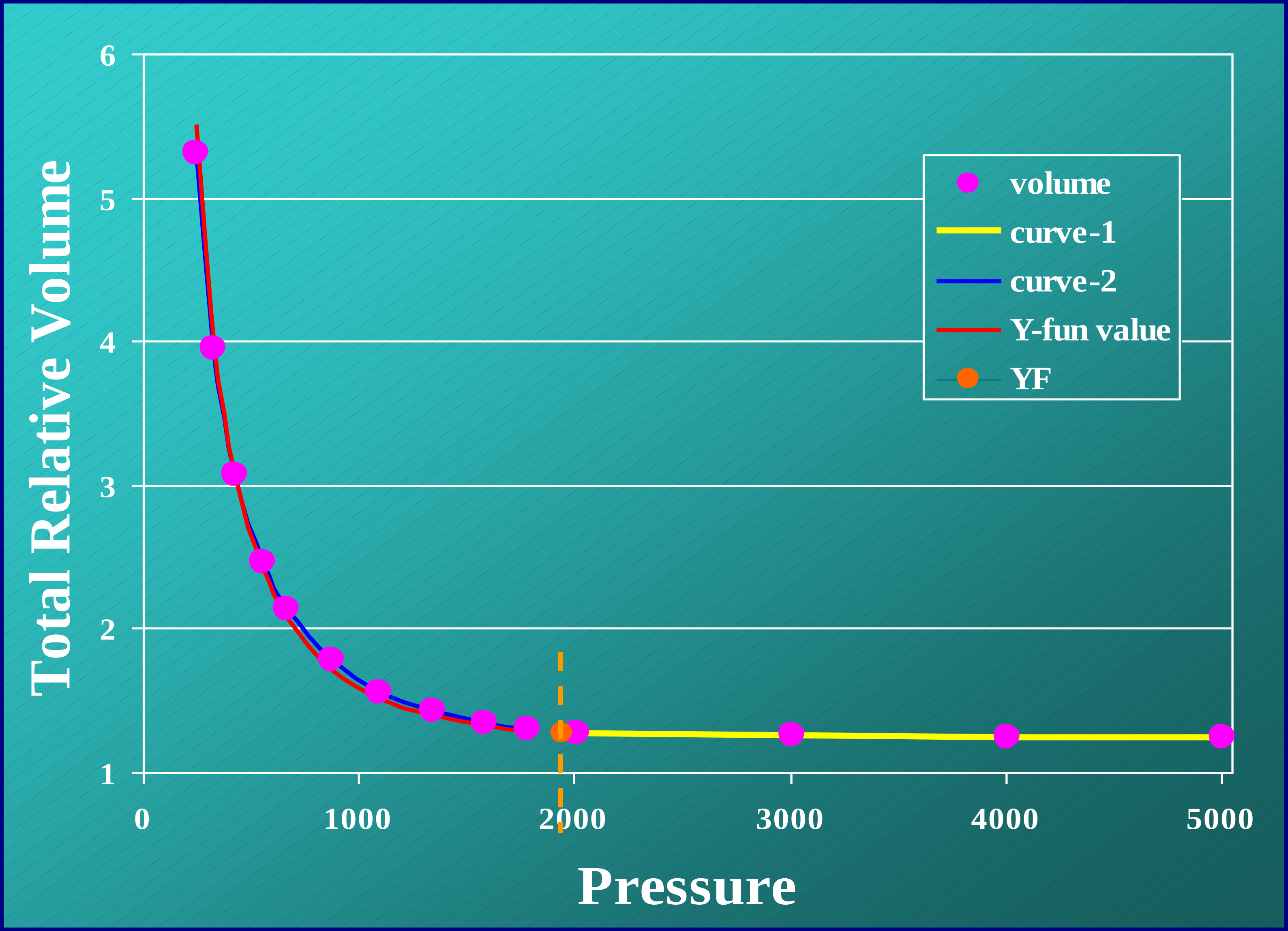
- To obtain P-V data, conduct a flash liberation experiment on a gas-oil mixture at a constant temperature
- Data analysis defines
  - volume & pressure at bubble point
  - FVF above p_b & total FVF below p_b
- The experimental data as reported are accompanied by measurement errors. Therefore, the data are usually smoothed

Y-function properties

- Only the experimental data at pressures below p_b are utilized to obtain p_b
- Bubble point volume is not corrected
- Y-Correlation with an error in the bubble point volume may yield a straight line but with the wrong p_b



Y–Function plot



Smoothing relative total volume data

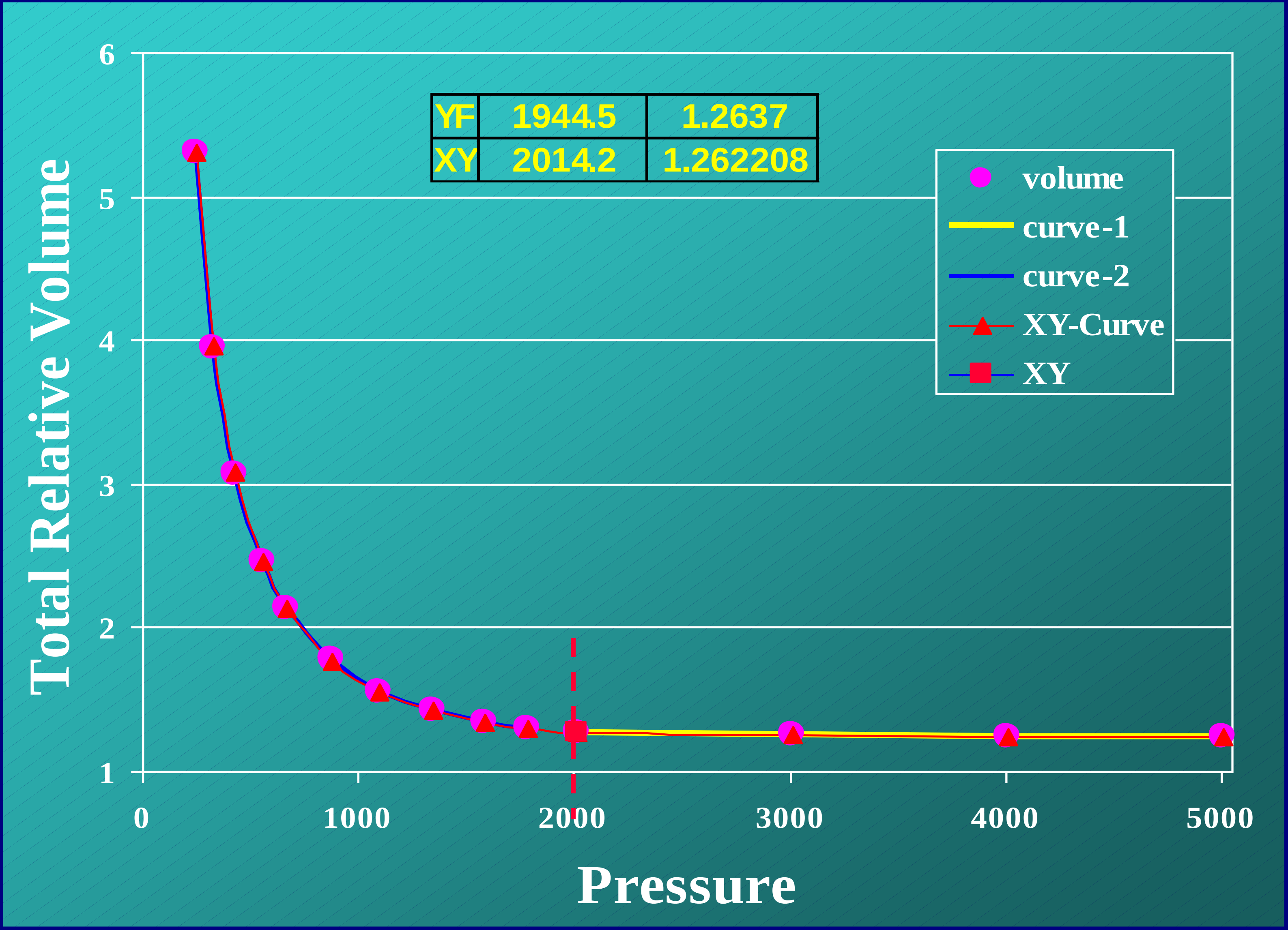
- **Current**

$$y = \frac{(p_b - p)/p}{(v_t - v_b)/v_b} = a_1 + a_2 p$$

- **Suggested: add x-function beside y-function**

$$x = \frac{(v_b - v_o)/v_b}{(p - p_b)/p_b} = a_3 + a_4 p$$

X-Y Function plot



Problems related to correlations

- Correlation application
- Properties of correlations
- Physical trends of correlations
- Pitfalls of least square method

Correlation application

Correlations normally used to determine:

- Bubble-point pressure, P_b
- Solution gas-oil ratios, R_s
- Density of liquids
- Oil FVF, B_{ob} & total FVF, B_t
- Adjustment of B_{ob} and R_s
- Oil compressibility, C_o
- Oil viscosity, μ_o , μ_a , μ_l
- Interfacial tension, σ

Properties of correlations

- Correlations typically match employed experimental data, with deviations less than a few percent
- When applied to other fluids, a much higher deviations are observed
- If fluids fall within the range of tested fluids, an acceptable accuracy can be expected
- Fluid composition could not be explained by gross properties
- Errors in some PVT correlations are not acceptable

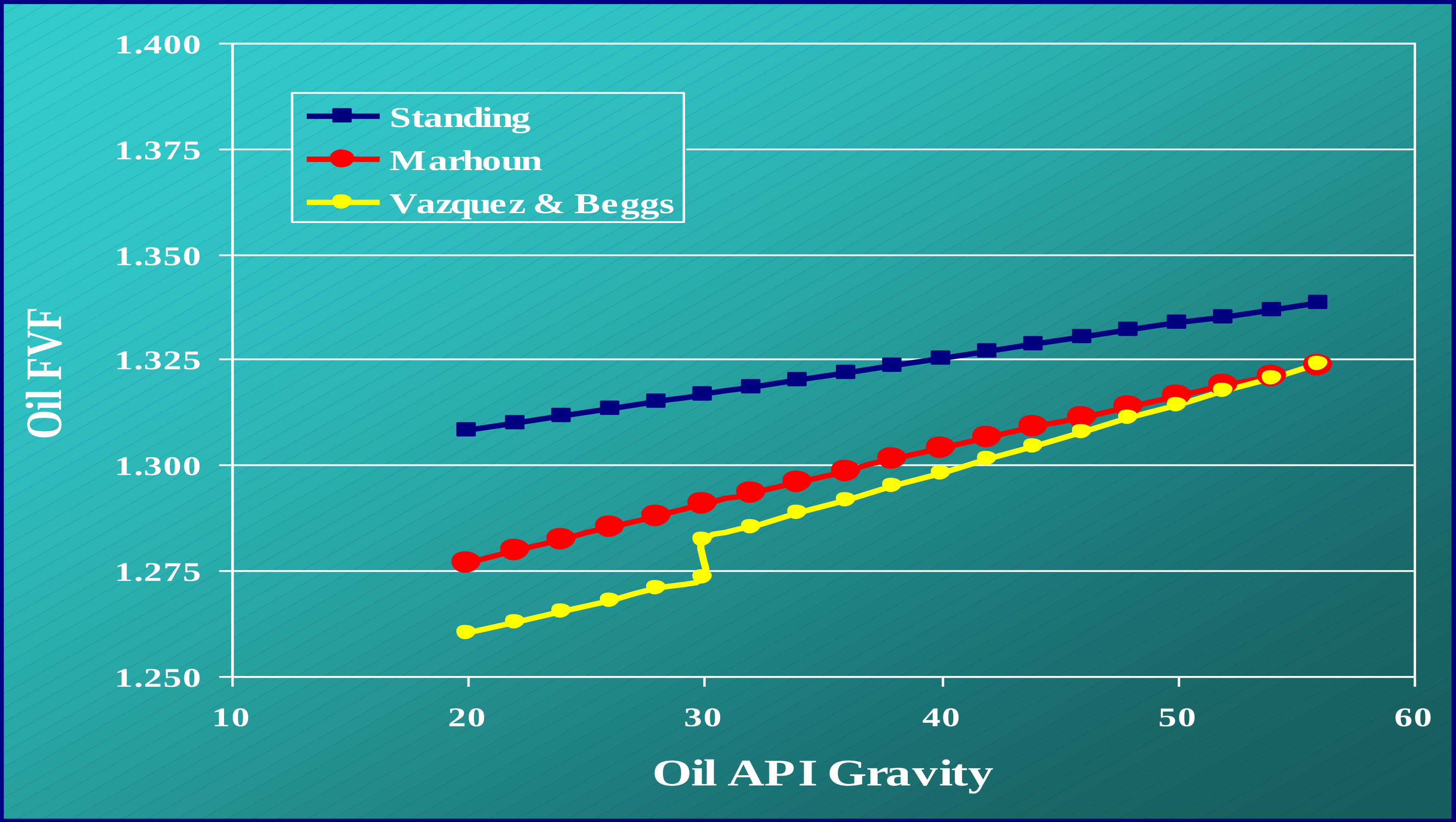
Physical trends of correlations

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

- **Trend tests on predicted values**
- **Trend tests on errors**

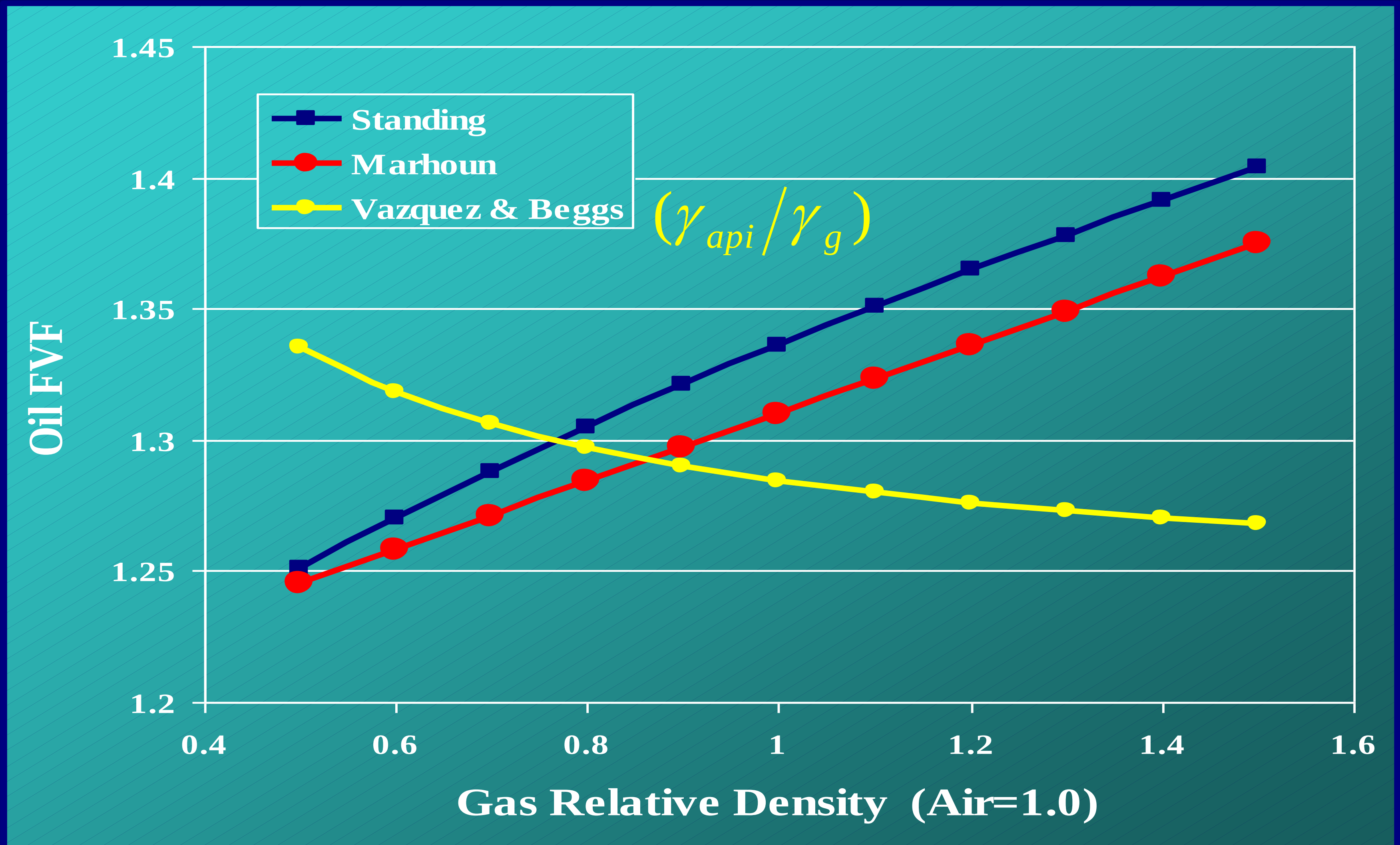
Correlation with two equations

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



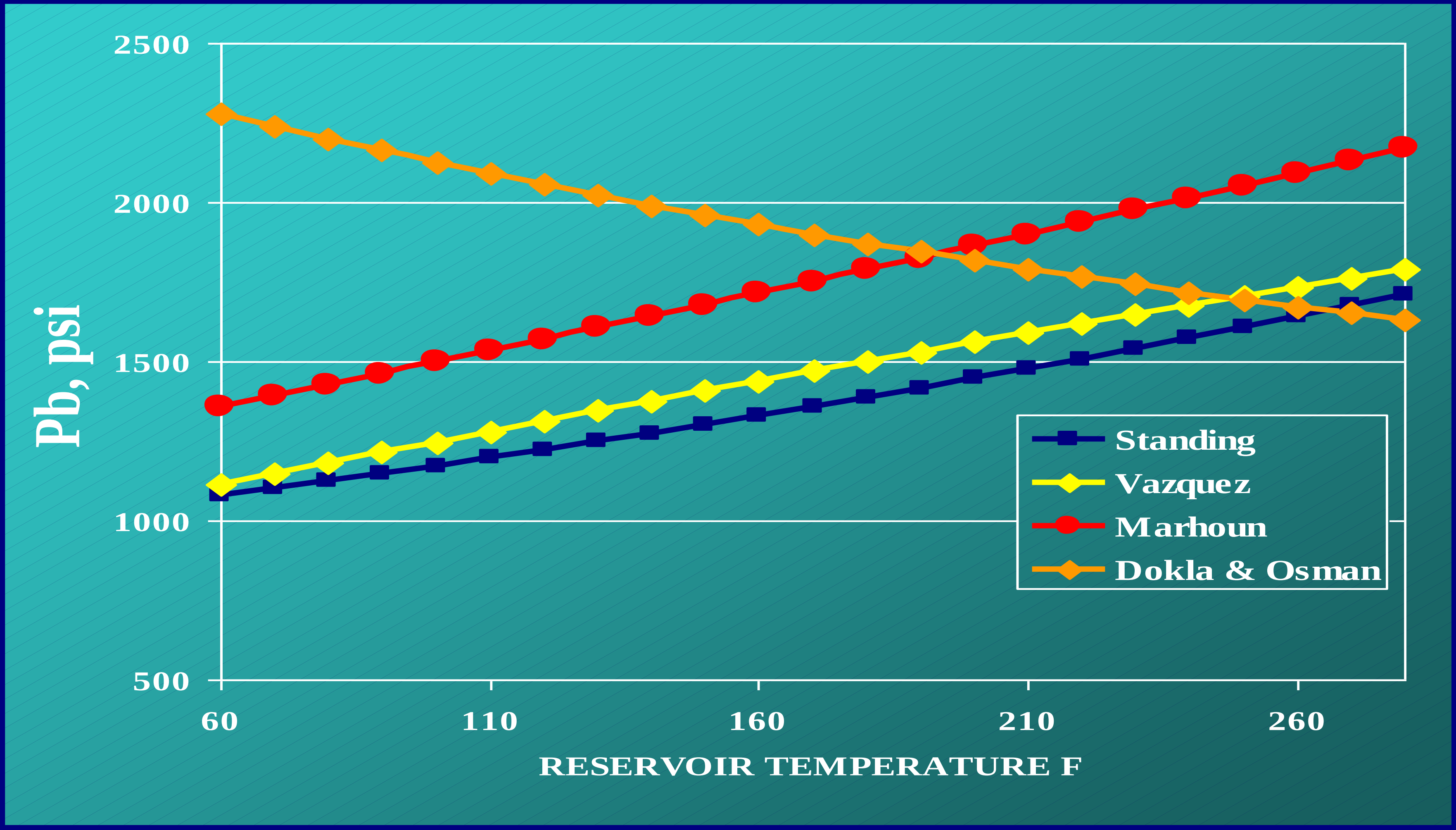
Correlation with non-physical constraint

- Restriction of correlation model gives non-physical trend

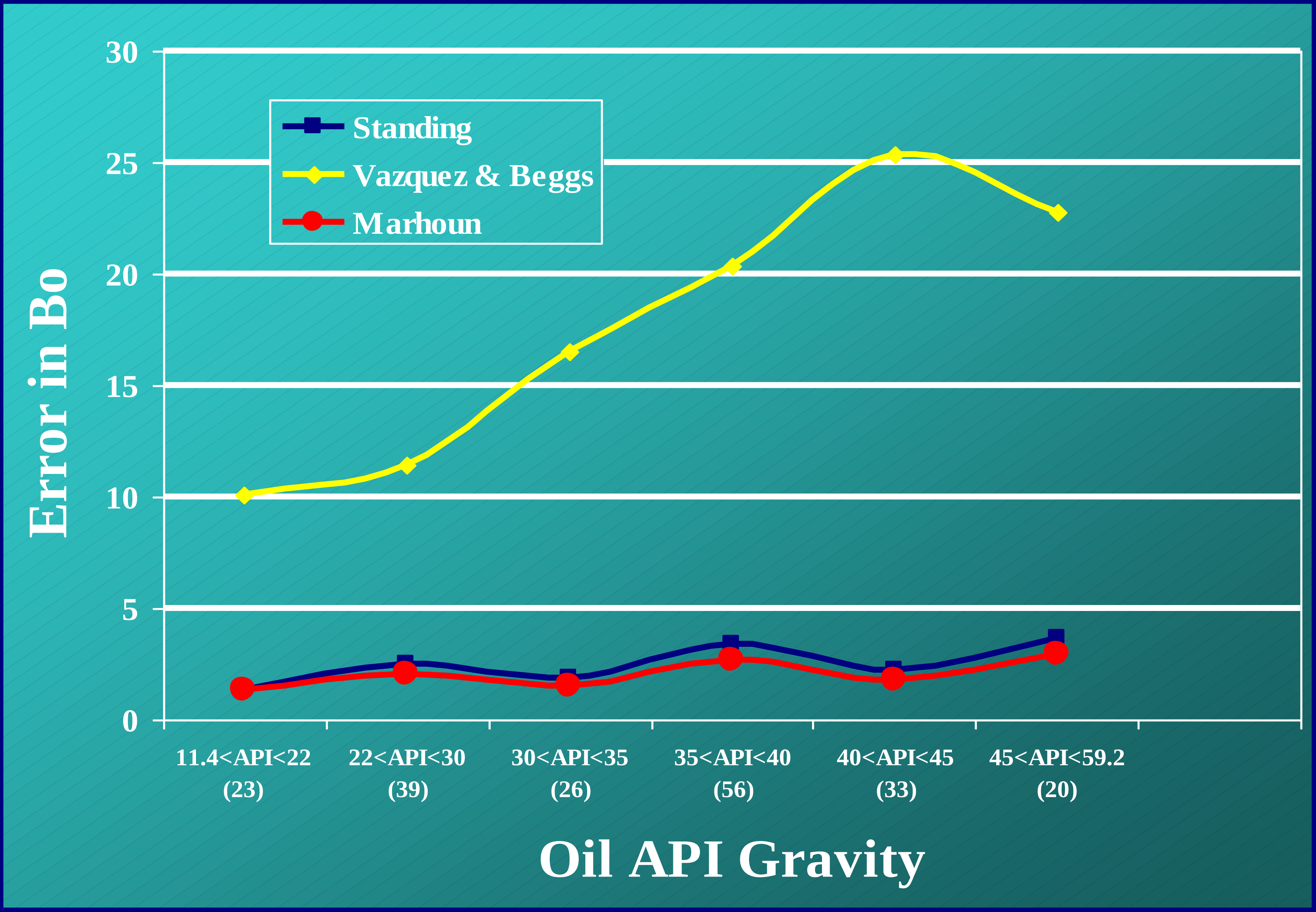


Correlation with limited data

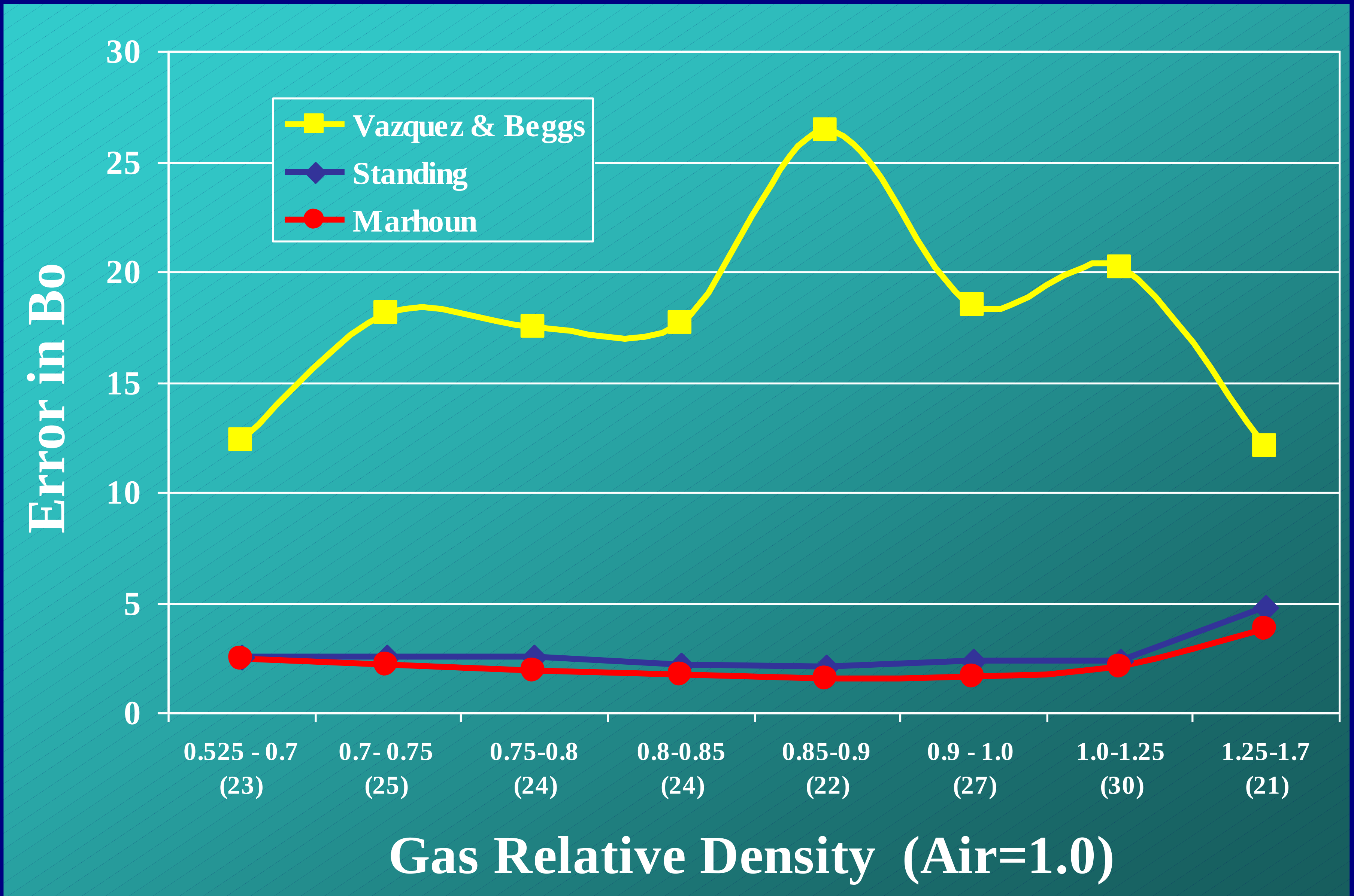
- Correlation development for limited data will give a good fit, but might lead to non-physical trend



Trend Tests on Error: Effect of API On B_{ob}



Trend Tests on Error: Effect of GRD On B_{ob}



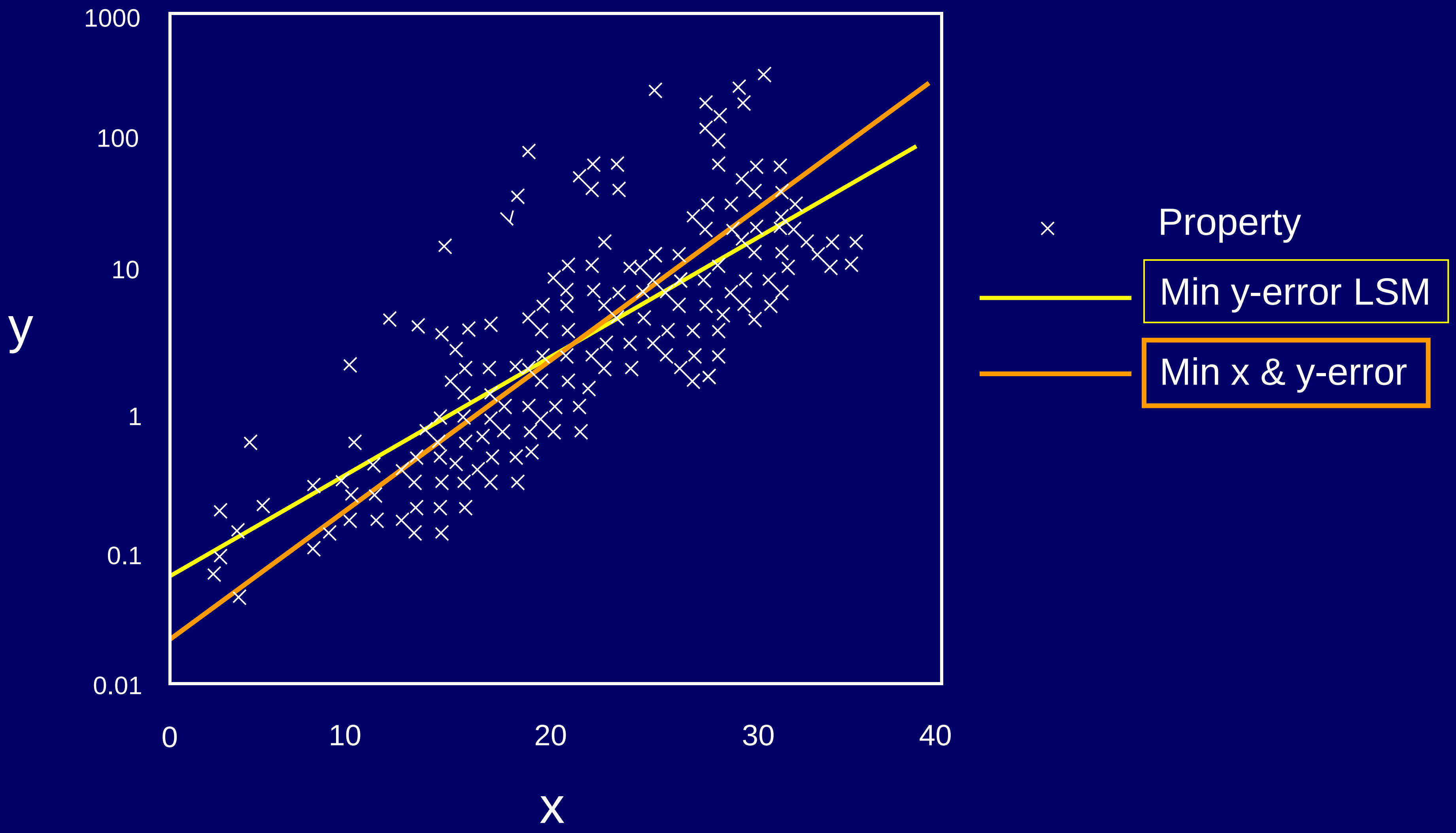
Pitfalls of least square method

Used to estimate the regression coefficients in model

$$y = f(x)$$

- Basic assumption of LSM is the independent variable x is determinate, i.e. it has no error
- But x and y involve measurement errors, therefore
- Do not rely entirely on a method when its basic assumption is violated

Comparison of the "Best fit line"



Pitfalls of logarithmic equivalence

logarithmic equivalent used to linearize equations

- Given the problem $y = kx^n$
- Use the logarithmic equivalent

$$\log y = \log k + n \log x$$

- Apply LSM to minimize error
- Compare errors $\Sigma\delta^2$

x	y
1	2.5
2	8.0
3	19.0
4	50.0

Comparative error analysis

Error using logarithmic equivalent

$$\delta = \log y(estimated) - \log y(given)$$

Error using original values

$$\delta = y(estimated) - y(given)$$

Method	k	n	$\Sigma\delta^2$ (logarithmic equivalent)	$\Sigma\delta^2$ (original problem)
LSM	2.224	2.096	0.02098	100.2
Iterative	0.474	3.36	0.56838	13.9

Artificial neural networks

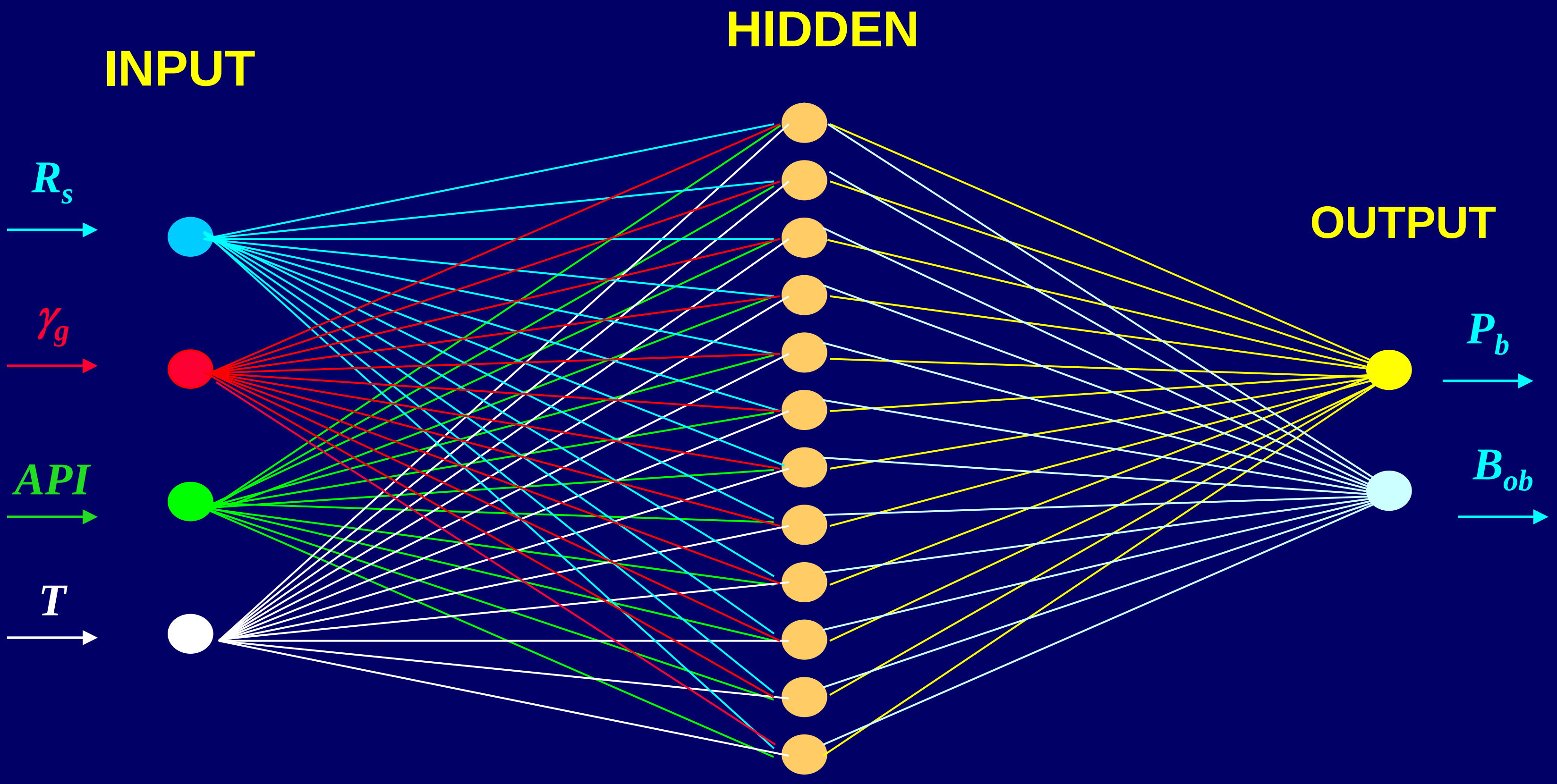
- Definition
- Advantages
- Problems & Challenges

Artificial neural networks

A mathematical model that can acquire artificial intelligence. It resembles brain in two respects by

- Acquiring knowledge through learning process
- Storing knowledge through assigning inter-neuron connection strengths known as weights

Neural network architecture



ANN Advantages

- Model function does not have to be known
- ANN learns behavior by self-tuning its parameters
- ANN has the ability to discover patterns
- ANN is fast-responding systems and provides a confident prediction
- ANN can accept more input to improve accuracy; such continuous enrichment or “knowledge” leads to more accurate predictive model

ANN Problems & Challenges

- Design of ANN:
  - Number of hidden layers
  - Number of neurons in each hidden layer
  - Learning constant to control speed of training

ANN Problems & Challenges

- Generalization Vs. Over Fitting
  - New training algorithms (cross validation)
  - Hybrid systems (expert systems)
  - Number of adjustable weights is large which is not justified unless the PVT data is huge
- Is the neural network the ultimate solution?

PVT Reporting

- Typical PVT report
- PVT report shortcoming
- Suggested improvement

Typical PVT Report

- Sampling information
- Hydrocarbon analysis of reservoir fluid
- Oil compressibility
- Pressure volume relationship (smoothed data)
- Differential liberation
- Separator tests
- Hydrocarbon analysis of lab flashed gases
- Liquid and gas viscosity data
- Mixture density

PVT Report- Shortcoming

- Reports smoothed results only
- Does not include raw data
- Does not verify data consistency

PVT Report -Suggested improvement

- Raw data reporting
  - Pressure volume (experimental data)
  - Differential liberation (experimental data)
  - Viscosity (experimental data)

- Data consistency
  - Mixture density calculation & verification
  - C_o calculation & verification

Conclusions

More improvement in the following areas:

- Problems related to experimentation
  - Reservoir process presentation
  - Physical trends of lab data
- Problems related to calculations
  - Adjustment of differential data
- Problems related to data smoothing
  - Y-function
  - XY-function

Conclusions

- Problems related to correlations
  - Physical trends of correlations
  - Pitfalls of least square method
- Artificial neural networks
  - Design of ANN
  - Over Fitting
- PVT Reporting
  - Raw data reporting
  - Data consistency

Final Comment

There are challenges in addressing these problems, but there are untapped scientific tools as well.

We explored these challenges and examined possible solutions.

Thank You