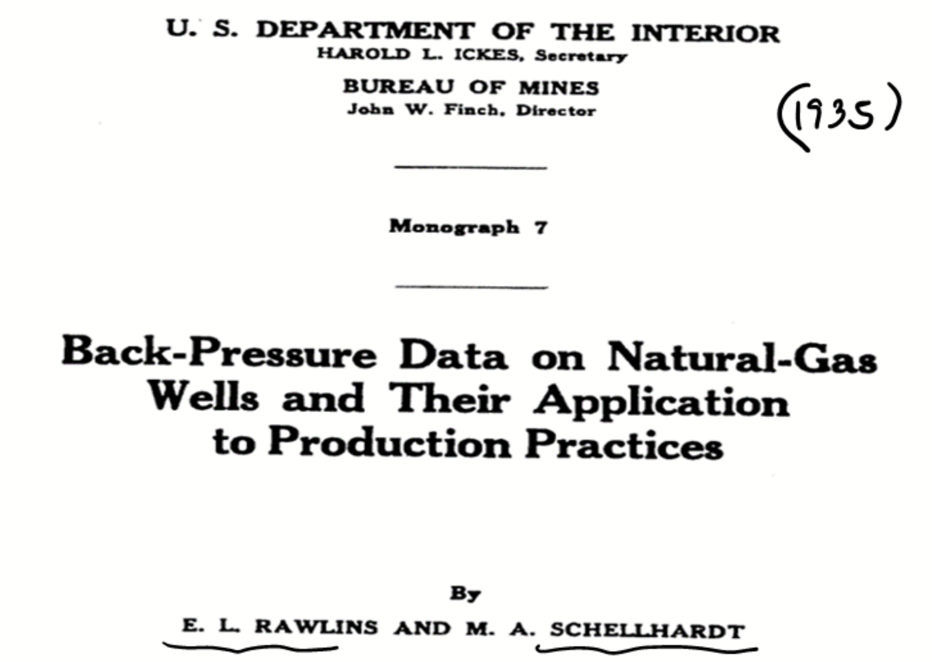


U. S. DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, Secretary

BUREAU OF MINES
John W. Finch, Director

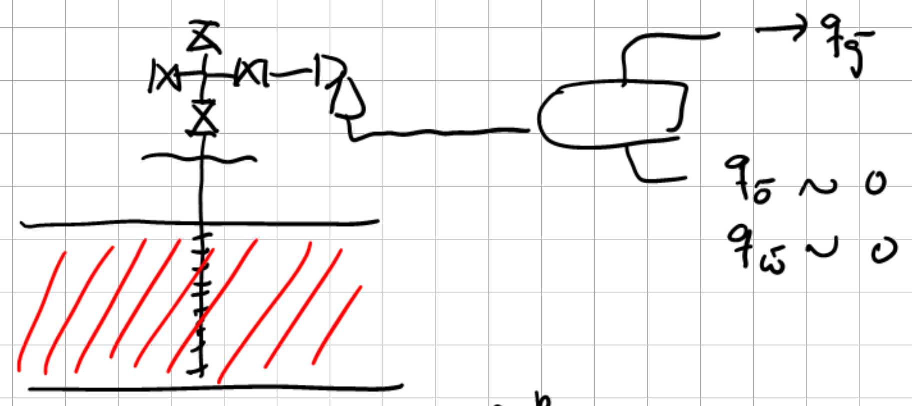
Monograph 7

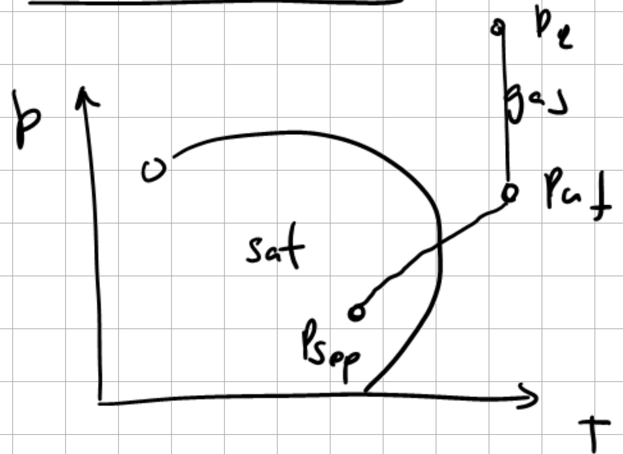
Back-Pressure Data on Natural-Gas Wells and Their Application to Production Practices

By

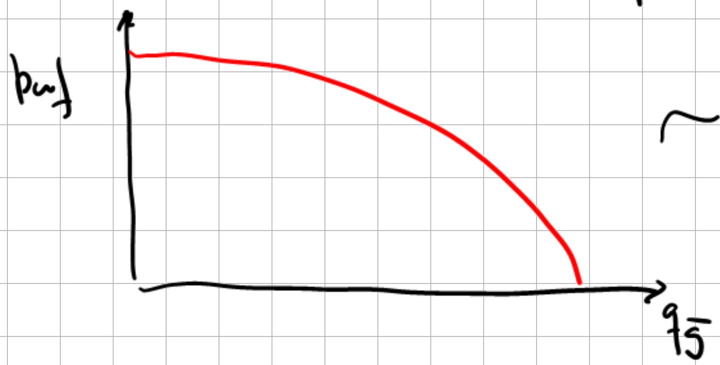
E. L. RAWLINS AND M. A. SCHELLHARDT

(1935)





Back-pressure equation



$$\sim \quad q_g = C\left(p_R^2 - p_{wf}^2\right)^n \rightarrow 0 \leq n \leq 1$$

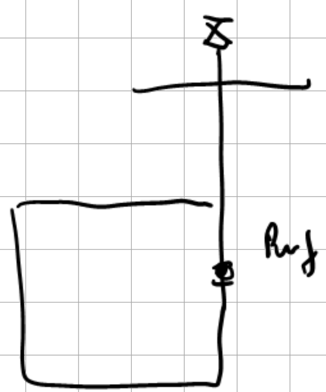
empirically, measured in the field

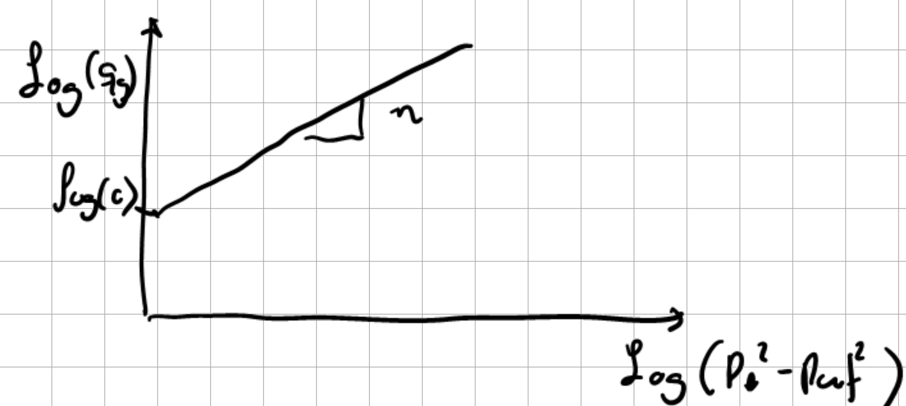
$$\frac{q_g}{C} = \left(p_R^2 - p_{wf}^2\right)^n \qquad \log$$

$$\log\left(\frac{q_g}{C}\right) = \log\left(\left(p_R^2 - p_{wf}^2\right)^n\right)$$

$$\log(q_g) - \log(C) = n \cdot \log\left(p_R^2 - p_{wf}^2\right)$$

$$\log(q_g) = \log(C) + n \log\left(p_R^2 - p_{wf}^2\right)$$





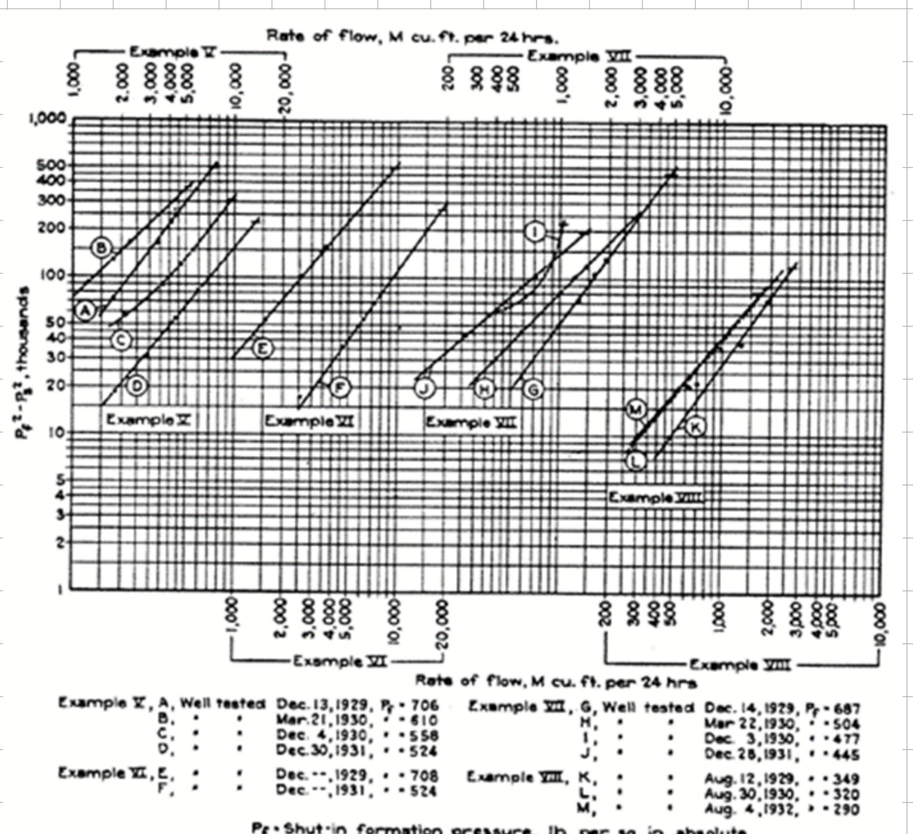
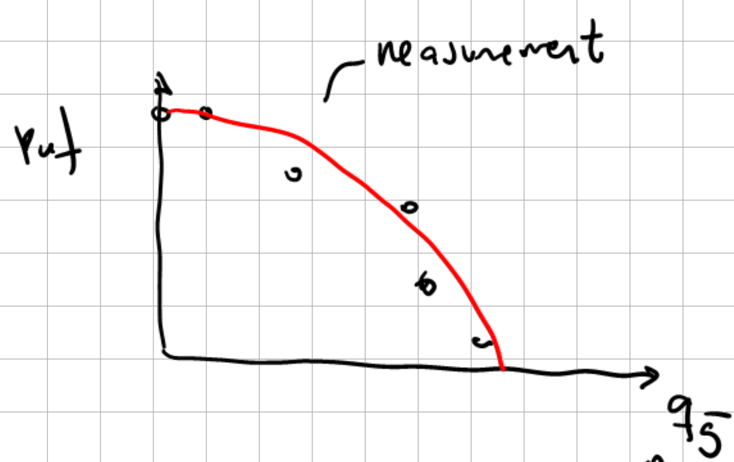


FIGURE 24.—Variation in delivery capacities of gas wells at different times in their productive lives, examples V, VI, VII, and VIII



$$q_g = C\left(p_R^2 - p_{wf}^2\right)^n$$

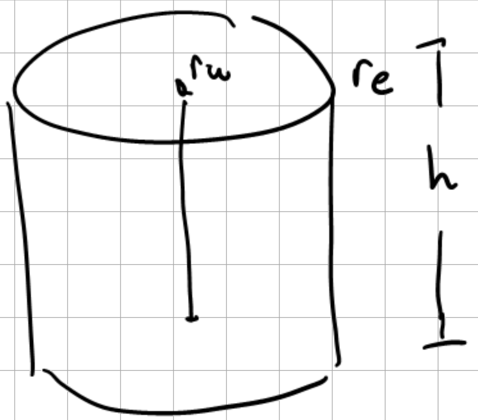
in Excel change C, n to match data

analytical derivation of Dry gas IPR

$q_{\bar{g}}$

$$v = \frac{k}{\mu_g}\frac{dp}{dr}$$

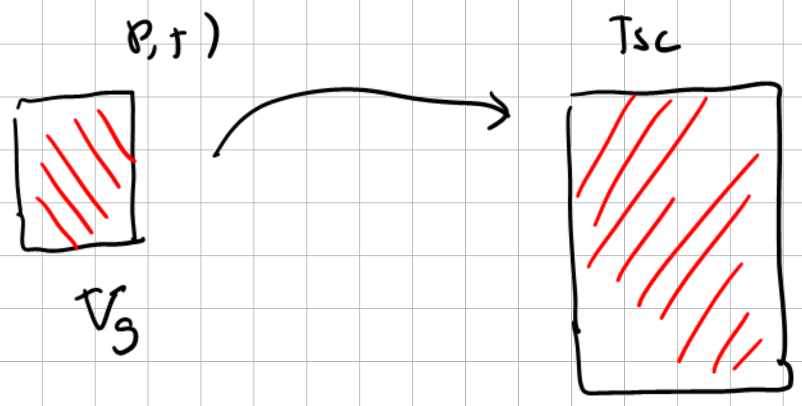
$$\frac{q_g}{2\pi r h} = \frac{k}{\mu_g}\frac{dp}{dr}$$



$$q_g = f(q_{\bar{g}})$$

$$B_g = \frac{q_g}{q_{\bar{g}}}$$

$$q_g = q_{\bar{g}} \cdot B_g$$



$$B_g = \frac{V_g}{V_{\bar{g}}}$$

gas volume factor

$$B_g = f(p, T)$$

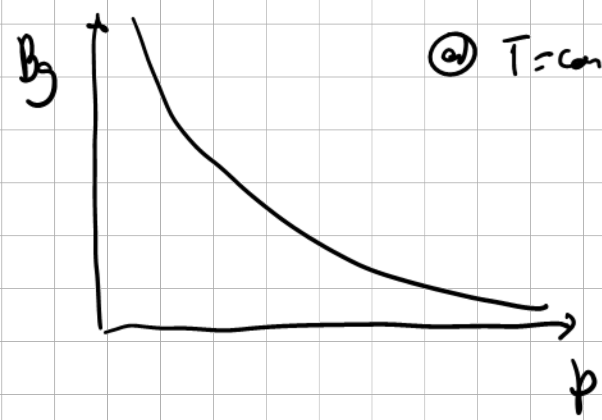
$$B_g \sim 1E\text{-}2 \rightarrow 1E\text{-}3$$

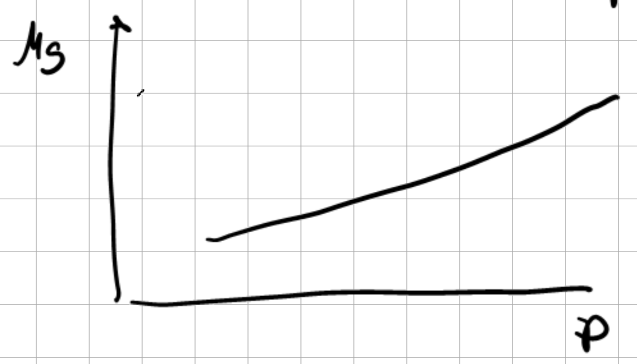
$$\int_{r_w}^{r_{@pR}} \frac{q_{\bar{g}}}{r} = \int_{p_{wf}}^{p_R} \frac{2\pi k h}{B_g \mu_g}\frac{dp}{dr}$$

for PSS

$$q_{\bar{g}} = \frac{2\pi k h}{\left(\ln\left(\frac{r_e}{r_w}\right) - 0.75\right)}$$

$$\int_{p_{wf}}^{p_R} \frac{1}{B_g \mu_g} dp \rightarrow ?$$





mass conservation

$$q_{\bar{g}} \cdot \rho_{\bar{g}} = q_g \rho_g$$

$$B_g = \frac{q_g}{q_{\bar{g}}} = \frac{\rho_{\bar{g}}}{\rho_g}$$

Real gas equation

$$\frac{p}{\rho} = zRT \qquad R = \frac{R_u}{MW}$$

↖ gas deviation factor ↘ deviation from ideal gas

$$\rho = \frac{p}{zRT}$$

Boyle (English)

Hooke (English)

Charles (French)

Gay-Lussac (French)

Avogadro (Italian)

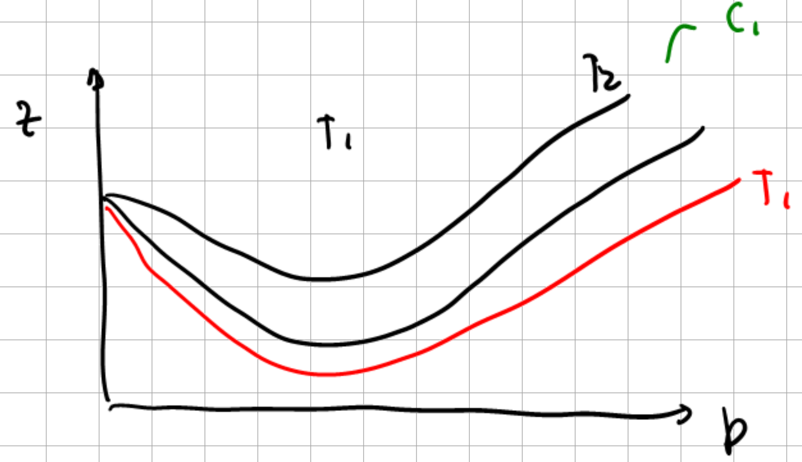
$z \sim$

Copyright, 1942 and 1943, by the
American Institute of Mining and Metallurgical Engineers
(Incorporated)

Density of Natural Gases

By Marshall B. Standing* and Donald L. Katz,* Member A.I.M.E.

(New York Meeting, February 1941)



$$T_r = \frac{T}{T_c} \qquad p_r = \frac{p}{p_c}$$

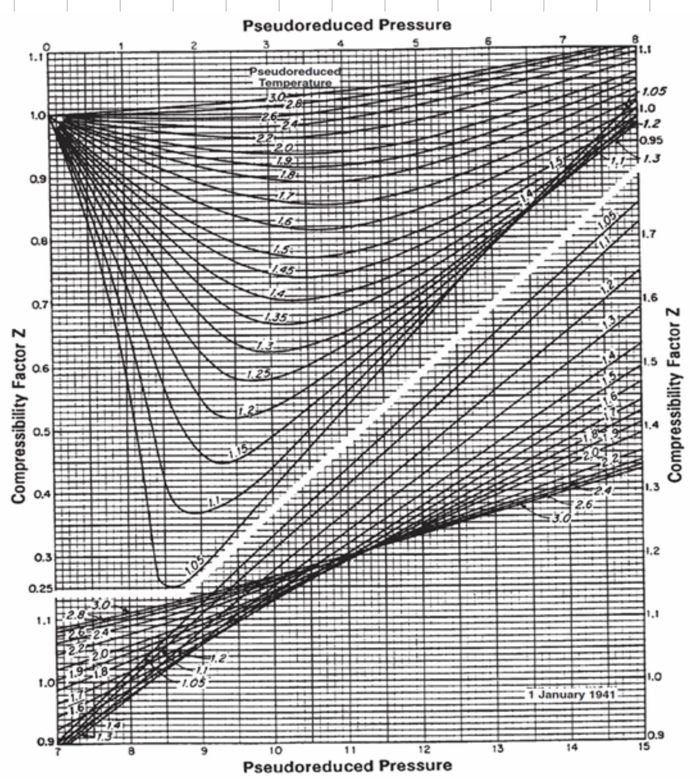
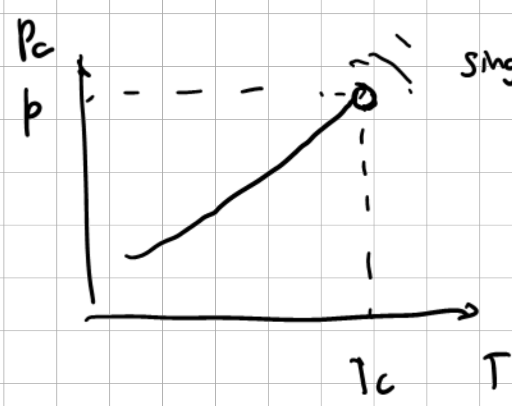


Fig. 3.6—Standing-Katz[4] Z-factor chart.

T_c, p_c

$T_c, p_c = f(MW)$



single component substance

Gas composition

Component	mole fraction
C_1	z_{C_1}
C_2	z_{C_2}
C_3	z_{C_3}
⋮	

$$\sum_{1}^{N} z_i = 1$$

$$MW_{mix} = \sum_{1}^{N} Mw_i z_i \qquad T_c, p_c = f(MW_{mix}) \rightsquigarrow \text{Sutton}$$

$$B_g = \frac{\rho_{\bar g}}{\rho_g} \qquad \rho_{\bar g} = \frac{p_{sc}}{z_{sc} R T_{sc}} \qquad \rho_g = \frac{p}{z R T}$$

$z_{sc} = 1$

$$B_g = \frac{p_{sc}}{T_{sc}} \cdot \frac{z T}{p}$$

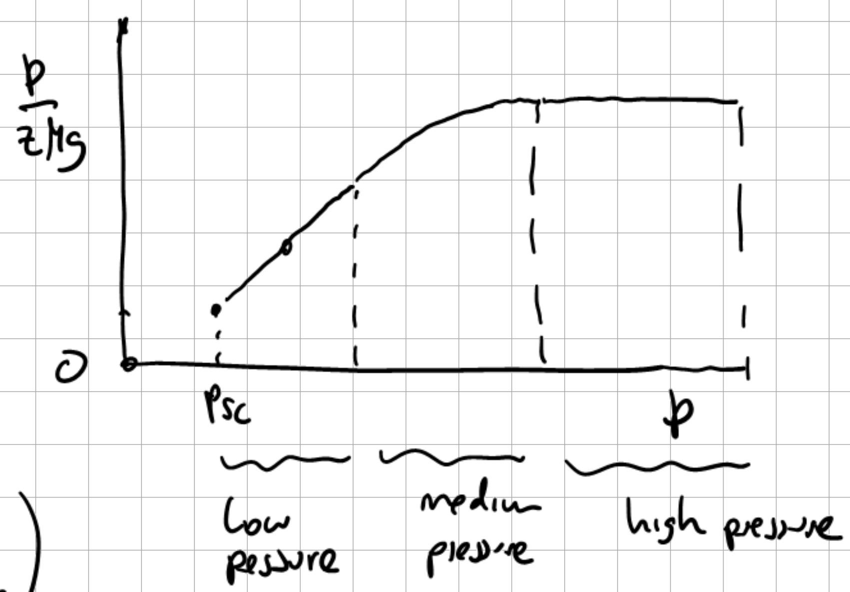
$$q_{\bar g} = \frac{2\pi k h}{\left(\ln\left(\frac{r_e}{r_w}\right) - 0.75\right)} \int_{p_{wf}}^{p_R} \frac{1}{\mu_g B_g} dp$$

p_{sc} 1.01325 bara

T_{sc} 15.56 °C

$T = T_R$

$$q_{\bar g} = \frac{2\pi k h}{\ln\left(\frac{r_e}{r_w} - 0.75\right)} \frac{T_{sc}}{p_{sc} T_R} \int_{p_{wf}}^{p_R} \frac{p}{z \mu_g} dp$$



low pressure (p_{wf}, p_R)

$$q_g = \frac{2\pi k h}{\left(\ln\frac{r_e}{r_w} - 0.75\right)} \frac{T_{sc}}{p_{sc} T_R} \, 0.5 \left[p_R^2 - p_{wf}^2\right] \left(\frac{1}{z\mu_g}\right)_{@ p_R}$$

in the low pressure region $\left(\frac{1}{\mu_g z}\right) = \text{const}$

$$q_{\bar g} = C\left(p_R^2 - p_{wf}^2\right)^n \quad \text{if } n = 1 \quad \text{it's a match!}$$

high pressure

$$q_{\bar g} = \frac{2\pi k h}{\left(\ln\left(\frac{r_e}{r_w}\right) - 0.75\right)} \frac{T_{sc}}{p_{sc} T_R} \left(\frac{p}{\mu B_g}\right)_{@} \int_{p_{wf}}^{p_R} dp = \frac{2\pi k h}{\left(\ln\frac{r_e}{r_w} - 0.75\right)} \frac{T_{sc}}{p_{sc} T_R} \frac{p_R}{(\mu_g z)_{@ p_R}} (p_R - p_{wf})$$

@ avg pressure; constant

similar to undersaturated oil IPR

doesn't resemble $q_{\bar g} = C\left(p_R^2 - p_{wf}^2\right)^n$

$$q_{\bar o} = J\,(p_R - p_{wf})$$