Natural Gas Compressibility Factor (Hall–Yarborough, Kay's Rule)

Compressibility factor and density of a natural gas from its composition (Kay's rule pseudo-critical properties) by the Hall–Yarborough equation of state.

Method: Hall and Yarborough (1973) equation of state on Standing–Katz Z; Kay's rule pseudo-critical properties; critical constants from the NIST Chemistry WebBook

Input parameters

Unit system: SI

Parameter	Value	Unit
Methane	90.000	%
Ethane	5.0000	%
Propane	2.0000	%
Carbon dioxide	1.0000	%
Nitrogen	2.0000	%
Pressure (absolute)	50.000	bar
Temperature	20.000	°C

Calculated results

Parameter	Value	Unit
Pseudo-critical temperature	-73.418	°C
Pseudo-critical pressure	46.093	bar
Compressibility factor	0.88511	
Gas density	41.311	kg/m³

Formula and method

$$T_{pc} = \sum y_i T_{c,i}, \quad p_{pc} = \sum y_i p_{c,i}, \quad t = \frac{T_{pc}}{T}, \quad p_{pr} = \frac{p}{p_{pc}}$$

$$A = 0.06125\, t\, e^{-1.2(1-t)^2}, \quad B = 14.76t - 9.76t^2 + 4.58t^3, \quad C = 90.7t - 242.2t^2 + 42.4t^3, \quad D = 2.18 + 2.82t$$

$$-Ap_{pr} + \frac{y + y^2 + y^3 - y^4}{(1-y)^3} - By^2 + Cy^D = 0, \quad Z = \frac{Ap_{pr}}{y}, \quad \rho = \frac{pM}{ZRT}$$

Variables

y_{CH_4}	Methane	-
$y_{C_2H_6}$	Ethane	-
$y_{C_3H_8}$	Propane	-
y_{CO_2}	Carbon dioxide	-
y_{N_2}	Nitrogen	-
p	Pressure (absolute)	Pa
T	Temperature	K
T_{pc}	Pseudo-critical temperature	K
p_{pc}	Pseudo-critical pressure	Pa
Z	Compressibility factor	-

ρ	Gas density	kg/m³
y_i	mole fraction of component i	-
$T_{c,i}\$, \$p_{c,i}$	critical temperature and pressure of component i (NIST)	K, Pa
t	reciprocal pseudo-reduced temperature, T_pc/T	-
p_{pr}	pseudo-reduced pressure	-
$A\$, \$B\$, \$C\$, \$D$	Hall–Yarborough coefficients	-
y	reduced density, the root of the equation	-
M	molar mass of the gas, Σ y_i M_i	kg/kmol
R	universal gas constant	J/(kmol·K)

Method and standards

Kay's rule gives the pseudo-critical temperature and pressure as mole-fraction averages of the components' critical constants; the Hall–Yarborough equation (a fit to the Standing–Katz chart) is solved for the reduced density y, taking the smallest root (the gas root), and Z = A p_pr / y.

Assumptions and limits

- Sweet natural gas; a warning is given above 2 % CO_2 (no Wichert–Aziz correction).
- The Hall–Yarborough equation is solved by scanning upwards for the first sign change and bisecting it; the result is rejected if it does not converge.
- Only methane, ethane, propane, CO_2 and N_2 are inputs. Butanes and heavier must be lumped into propane, a rough approximation; for a rich gas use a full equation of state such as AGA 8.
- CO_2 above 2 % gives a warning; the fractions are not limited.

References

• Hall and Yarborough (1973) equation of state on Standing–Katz Z; Kay's rule pseudo-critical properties; critical constants from the NIST Chemistry WebBook

Report details

Report reference	FCC-D31N-2004 (the same inputs always give the same reference)
Generated	17 November 2026, 19:50 UTC
Calculator	Natural Gas Compressibility Factor (Hall–Yarborough, Kay's Rule)
Method last reviewed	13 November 2026
Software release	FireCAD Calc, release of 17 November 2026
Release checks	2 reference cases of this calculator, computed independently, are checked on every release

Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/boilers-power-plant/combustion/natural-gas-z-factor

Open this case on calc.firecad.com →

Reopens the calculator with the inputs of this report.