Flue Gas and Air Properties

Density, specific heat, enthalpy, viscosity, thermal conductivity and Prandtl number of a flue gas or air mixture at temperature, from NIST data and kinetic-theory mixing rules.

Method: NIST-JANAF Shomate heat capacities; Sutherland viscosity; ...

Input parameters

Unit system: SI

Parameter	Value	Unit
Gas temperature	150.00	°C
Absolute pressure	1.0132	bar
Oxygen (O2)	4.0000	%
Nitrogen (N2)	74.800	%
Carbon dioxide (CO2)	13.000	%
Water vapour (H2O)	8.0000	%
Sulphur dioxide (SO2)	0.20000	%
Carbon monoxide (CO)	0	%
Hydrogen (H2)	0	%
Argon (Ar)	0	%

Calculated results

Parameter	Value	Unit
Molar mass	29.525	kg/kmol
Normal density (0 °C, 101.325 kPa)	1.3173	kg/m³
Density at T and p	0.85031	kg/m³
Specific heat capacity at T	1.0655	kJ/(kg·K)
Mean specific heat 25 °C → T	1.0500	kJ/(kg·K)
Enthalpy above 25 °C	131.25	kJ/kg
Dynamic viscosity	2.2064e-05	Pa·s
Kinematic viscosity	2.5949e-05	m²/s
Thermal conductivity	0.030990	W/(m·K)
Prandtl number	0.75861	

Formula and method

$$M = \sum_i y_i M_i \qquad \rho = \frac{p\,M}{R\,T} \qquad \rho_n = \frac{M}{V_m} \qquad c_p = \frac{\sum_i y_i\,C_{p,i}(T)}{M} \qquad h = \int_{T_{ref}}^{T} c_p\,dT \qquad \bar{c}_p = \frac{h}{T - T_{ref}}$$

$$C_{p,i} = A + Bt + Ct^2 + Dt^3 + \frac{E}{t^2}$$

$$\mu_i = \mu_{0,i}\left(\frac{T}{T_{0,i}}\right)^{3/2}\frac{T_{0,i} + S_i}{T + S_i} \qquad \mu = \sum_i \frac{y_i\,\mu_i}{\sum_j y_j\,\Phi_{ij}} \qquad \Phi_{ij} = \frac{\left[1 + (\mu_i/\mu_j)^{1/2}(M_j/M_i)^{1/4}\right]^2}{\sqrt{8\,(1 + M_i/M_j)}}$$

$$k_i = \mu_i \left(c_{p,i} + \frac{5}{4}\frac{R}{M_i} \right) \qquad k = \sum_i \frac{y_i\, k_i}{\sum_j y_j\, \Phi_{ij}} \qquad \nu = \frac{\mu}{\rho} \qquad Pr = \frac{c_p\, \mu}{k}$$

Variables

T	gas temperature	K
p	absolute pressure	Pa
y_i	volume (mole) fraction of species *i*: y_{O_2}, y_{N_2}, y_{CO_2}, y_{H_2O}, y_{SO_2}, y_{CO}, y_{H_2}, y_{Ar}	–
$M_i$$, $$M$	molar mass of species *i* and of the mixture	kg/kmol
R	universal gas constant, 8 314.46	J/(kmol·K)
V_m	molar volume at 0 °C and 101.325 kPa, 22.414	m³/kmol
ρ_n	density at normal conditions	kg/Nm³
ρ	density at T and p	kg/m³
$C_{p,i}$	molar heat capacity of species *i*	J/(mol·K)
c_p	specific heat capacity of the mixture at T	J/(kg·K)
$\bar{c}_p$	mean specific heat between 25 °C and T	J/(kg·K)
h	enthalpy above 25 °C	J/kg
$\mu_i$$, $$\mu$	dynamic viscosity of species *i* and of the mixture	Pa·s
ν	kinematic viscosity	m²/s
$k_i$$, $$k$	thermal conductivity of species *i* and of the mixture	W/(m·K)
Pr	Prandtl number	–
T_{ref}	reference temperature for enthalpy, 298.15	K

Method and standards

The same formulations FireCAD uses in its boiler design software: NIST-JANAF Shomate polynomials for heat capacity (NIST Chemistry WebBook), Sutherland's law for each species' viscosity, Wilke's 1950 rule for the mixture viscosity, the Eucken relation for each species' conductivity except water vapour, whose conductivity is the dilute-gas term of the IAPWS 2011 formulation (R15-11), and the Wassiljewa equation with Mason–Saxena coefficients for the mixture conductivity. Enthalpy is the numerical integral (composite Simpson rule, steps of 10 K or less) of the Shomate heat capacity from 25 °C, the ASME PTC 4 reference temperature.

Assumptions and limits

- Ideal gas (fine for flue gas and air below about 20 bar); a warning appears above 20 bar.
- 250–2 500 K. Water vapour heat capacity below 500 K extrapolates the NIST fit by less than 1 %; the SO_2, CO, CO_2, H_2 and Ar fits start at 298 K and are extrapolated slightly below it (a note appears).
- Transport mixing rules are accurate to a few per cent for viscosity; the mixture conductivity of water-rich gas is within a few per cent; they are not valid for condensing gas. A warning is given when the water vapour partial pressure exceeds the IAPWS-IF97 saturation pressure at the gas temperature (below the dew point).

References

- NIST-JANAF Shomate heat capacities
- Sutherland viscosity
- Wilke (1950) mixing rule
- Eucken relation
- IAPWS R15-11 (2011) dilute-gas conductivity of water vapour
- Mason–Saxena mixing

Report details

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Release checks	3 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/gas-properties

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Reopens the calculator with the inputs of this report.