Thermal Oxidiser: Residence Time, VOC Destruction and Fuel

Residence time, VOC destruction efficiency from Arrhenius kinetics and fuel needed by a thermal oxidiser, with recuperative or regenerative heat recovery.

Method: Cooper and Alley; Air Pollution Control: A Design Approach; ...

Input parameters

Unit system: SI

Parameter	Value	Unit
Gas flow at 0 °C, 1 atm	10,000	Nm³/h
Inlet gas temperature	30.000	°C
Combustion chamber temperature	760.00	°C
Chamber volume	8.0000	m³
Heat recovery effectiveness (0 none, 0.6–0.7 recuperative, 0.95 regenerative)	95.000	%
Gas specific heat	1.1000	kJ/(kg·K)
$\log_{10}$ of the VOC rate constant A (1/s)	13.358	
Activation energy	236.40	kJ/mol
Fuel net calorific value	50.000	MJ/kg

Calculated results

Parameter	Value	Unit
Actual flow at the chamber temperature	37,824	m³/h
Residence time	0.76143	s
Rate constant at T_c	25.479	1/s
Destruction efficiency	100.000	%
Gas temperature after heat recovery	723.50	°C
Burner heat	144.13	kW
Fuel	10.377	kg/h

Notes for this case

• Mixing, not kinetics, usually limits real oxidisers: design for 0.5–1 s at 760–870 °C (more for halogenated VOCs) and the permit's destruction efficiency. Burner heat is the sensible heat to raise the gas from T_pre to T_c with all the fuel's net heat available: burner and shell losses, VOC heat release (which lowers the fuel) and the added combustion products are neglected. Defaults: toluene kinetics as quoted by Cooper and Alley.

Formula and method

$$\tau = \frac{V}{Q_a}, \quad k = A e^{-E/RT_c}, \quad DRE = 1 - e^{-k\tau}, \quad T_{pre} = T_{in} + \varepsilon(T_c - T_{in}), \quad Q_f = \dot{m} c_p (T_c - T_{pre})$$

Variables

Q_n	Gas flow at 0 °C, 1 atm	Nm³/s
T_{in}	Inlet gas temperature	K
T_c	Combustion chamber temperature	K
V	Chamber volume	m³
$\mathcal{E}$	Heat recovery effectiveness (0 none, 0.6–0.7 recuperative, 0.95 regenerative)	-
c_p	Gas specific heat	J/(kg·K)
$\log_{10} A$	$\log_{10}$ of the VOC rate constant A (1/s)	-

E	Activation energy	J/mol
LHV	Fuel net calorific value	J/kg
Q_a	Actual flow at the chamber temperature	m³/s
$\mathcal{T}$	Residence time	s
k	Rate constant at T_c	1/s
DRE	Destruction efficiency	-
T_{pre}	Gas temperature after heat recovery	K
Q_f	Burner heat	W
$\dot{m}_f$	Fuel	kg/s

Method and standards

Plug-flow first-order oxidation and heat balance.

Assumptions and limits

- Fuel heat balance: Q_f = ṁ c_p (T_c − T_pre) with ṁ = 1.293 kg/Nm³ × Q_n, the whole net calorific value available, no burner or casing losses, no heat from the VOC itself and no extra flue gas from the fuel. At high VOC loading the VOC heat can cut the fuel substantially; losses raise it.
- Plug flow; first-order kinetics.

References

• Cooper and Alley
• Air Pollution Control: A Design Approach
• 4th ed. (Waveland, 2011)
• ch. 13 (thermal oxidation: Arrhenius kinetics, residence time and fuel)

Report details

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