Flame Speed Problem

Thursday, October 12, 2017 11:53 AM

Estimate the laminar flame speed of a stoichiometric propane-air mixture using the simplified theory result. Use the global one-step reaction mechanism below to estimate the mean reaction rate.

$d[C_3H_8]/dt = -k_G [C_3H_8]^{0.1}[O_2]^{1.6}$

$k_G = 4.836 * 10^9 * \exp(-15{,}098/T) \quad (\text{kmol/m}^3)^{-0.75}\ /\text{s}$

$T_{ad,C3H8} = 2260\ \text{K}$

$MW_{O2} = 32.0$ kg/kmol

$MW_{N2} = 28.01$ kg/kmol

$MW_{C3H8} = 44.10$ kg/kmol

$$\bar{T} = \frac{1}{2}\left(\frac{T_b + T_u}{2} + T_b\right)$$

$T_u = 300\text{K} \qquad T_b = 2260\text{K}$

$$\bar{T} = \frac{1}{4}(2560) + \frac{1}{2}(2260)$$

$$= 1770\text{K}$$

$Y_{F,\delta} = 0$

$Y_{ox,\delta} = 0$

$$\bar{Y}_{C_3H_8} = \frac{1}{2}\left(Y_{C_3H_8,u} + 0\right) = \frac{1}{2} Y_{C_3H_8,u}$$

$$C_3H_8 + \overset{5}{x} O_2 \rightarrow \overset{3}{y} CO_2 + \overset{4}{\cancel{z}} H_2O$$

$$3O_2 + 2O_2$$

$$Y_{C_3H_8,u} = \frac{1(MW_{C_3H_8})}{1(MW_{C_3H_8}) + 5(MW_{O_2}) + \frac{79}{21}5(MW_{N_2})}$$

$$= 0.06015$$

$$\bar{Y}_{C_3H_8} = \frac{1}{2} Y_{C_3H_8,u} = 0.0301$$

$$\bar{Y}_{O_2} = \frac{1}{2}\left(Y_{O_2,u} + \cancelto{0}{Y_{O_2,B}}\right) = \frac{1}{2} Y_{O_2,u}$$

$$Y_{O_2,u} = \frac{5(32)}{\Sigma N_i MW_i}$$

$$= 0.219$$

$$\bar{Y}_{O_2} = 0.1695$$

$$a = \frac{\text{kg oxidizer}}{\text{kg fuel}} = \frac{5\, MW_{O_2} + \frac{79}{21} 5\, MW_{N_2}}{MW_F}$$

$$= 15.625$$

$$\dot{\omega}_F = \frac{d[C_3H_8]}{dt} = -k_G [C_3H_8]^{0.1} [O_2]^{1.65}$$

$$k_G = 4.836 \times 10^9 e^{(-15098/T)}$$

$$= 9.55 \times 10^{5} \underline{\left(\text{kmol}/m^3\right)^{-0.75}} \frac{1}{s}$$

$$[C_3H_8] = \left(\frac{P}{R_uT}\right) \frac{Y_{C_3H_8}}{MW_{C_3H_8}} \left(\overline{MW}\right)$$

$$\bar{\rho} = \overline{MW} \left(\frac{P}{R_uT}\right)$$

$$\overline{MW} = \frac{1}{2}\left(MW_B + MW_u\right)$$

$$MW_u = \frac{5(MW_{O_2}) + 1(MW_{C_3H_8}) + 5\frac{79}{21} MW_{N_2}}{1 + 5 + 5\frac{79}{21}}$$

$$= 29.46 \text{ kg/kmol}$$

$$MW_B = \frac{3(MW_{CO_2}) + 4(MW_{H_2O}) + 5\frac{79}{21} MW_{N_2}}{3 + 4 + 5\frac{79}{21}}$$

$$= 28.32 \text{ kg/kmol}$$

$$\overline{MW} = \frac{1}{2}(MW_u + MW_B) = 28.89 \text{ kg/kmol}$$

$$\bar{\rho} = \overline{MW}\left(\frac{P}{R_uT}\right) = 28.89\left(\frac{101325 \text{ Pa}}{(8315)\,1770}\right)$$

$$= 0.1989 \text{ kg/m}^3$$

$$[C_3H_8] = \frac{\overline{Y_{C_3H_8}}}{MW_{C_3H_8}} \bar{\rho} = 0.0001360 \text{ kmol/m}^3$$

$$[O_2] = \frac{\overline{Y_{O_2}}}{MW_{O_2}} \bar{\rho} = 0.0006806 \text{ kmol/m}^3$$

$$\overline{\dot{\omega}}_{C_3H_8} = -k_G [C_3H_8]^{0.1} [O_2]^{1.65}$$

$$= -2.331 \text{ kmol}/m^3\text{-s}$$

$$\overline{\dot{m}}'''_F = \overline{\dot{\omega}}_{C_3H_8}\, MW_{C_3H_8} = -102.6 \frac{kg}{m^3}$$

$\underline{\sim 1280\text{ K}}$

$k = 0.0809$ kJ/m-s-K

$c_p = 1.186$ kJ/kg-K

$\rho_u = 1.16$ kg/m^3

$$\bar{T} = \frac{1}{2}(T_b + T_u) = 1280\text{ K}$$

$$\alpha = \frac{k}{\rho_u c_p} = 5.89 \times 10^{-5} \text{ m}^2/\text{s}$$

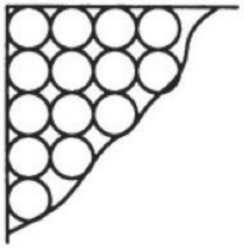
$$S_L = \left[-2\alpha\,(a+1)\frac{\overline{\dot{m}}'''_{C_3H_8}}{\rho_u}\right]^{1/2}$$

$$= 0.416 \text{ m/s or } \boxed{41.6 \text{ cm/s}}$$

Quenching Problem

Tuesday, October 24, 2017 10:48 AM

Consider the design of a laminar-flow, adiabatic, flat-flame burner consisting of a square arrangement of thin walled tubes as illustrated in the sketch below. Fuel-air mixture flows through both the tubes and the interstices between the tubes. It is desired to operate the burner with a stoichiometric methane-air mixture exiting the burner tubes at 300 K and 5 atm.



Burner tube layout

$R_u = 0.08206$ atm-m^3/kmol-K
$MW_{methane} = 16.04$ kg/kmol
$MW_{air} = 28.85$ kg/kmol

A) Determine the mixture mass flowrate per unit cross-sectional area at the design condition.

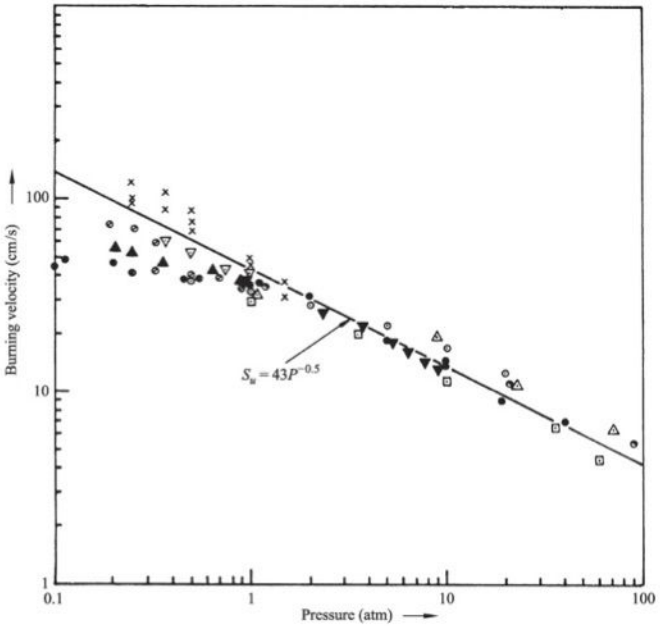


Figure 8.14 Effect of pressure on laminar flame speeds of stoichiometric methane–air mixtures for $T_u = 16$–27°C.

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$$\dot{m}'' = \rho_u S_L$$

$$S_L\,(300\text{ K}, 5\text{ atm}) = 43/\sqrt{5}$$

$= 19.2 \text{ cm/s}$

ρ_u: $\rho_u = \dfrac{P}{(R_u/MW_{mix})T_u}$

$MW_{mix} = X_F \, MW_F + (1 - X_c) \, MW_{air}$

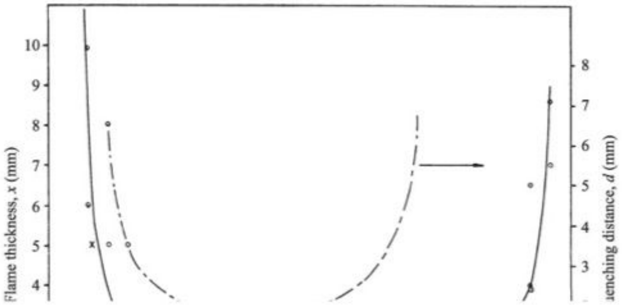
$CH_4 + 2O_2 \rightarrow prod$

$X_F = 1 / \left(1 + 2 + 2\frac{79}{21}\right) = \frac{1}{10.52} = 0.095$

$MW_{mix} = 27.6 \text{ kg/kmol} \Rightarrow \rho_u = 5.61 \frac{kg}{m^3}$

$\dot{m}'' = 1.08 \frac{kg}{s\text{-}m^2}$

1. **Estimate the maximum tube diameter allowed so that flashback will be prevented.**



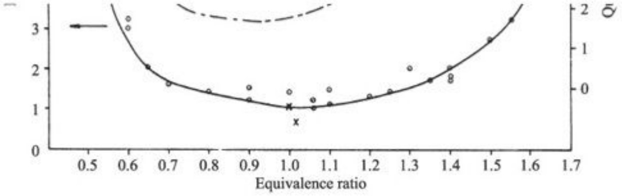


Figure 8.16 Flame thickness for laminar methane–air flames at atmospheric pressure. Also shown is the quenching distance.

SOURCE: Reprinted with permission, Elsevier Science, Inc., from Ref. [19], © 1972, The Combustion Institute.

$$\frac{d_1}{d_2} = \frac{\cancel{2\sqrt{b}}\, \alpha_1 / S_{L_1}}{\cancel{2\sqrt{b}}\, \alpha_2 / S_{L_2}}$$

State 1: $P = 5 \text{atm}$
$T_u = 300 \text{ K}$
$S_L = 19.2 \text{ cm/s}$

State 2: $P = 1 \text{ atm}$
$T_u = 300 \text{ K}$
$S_L = 43 \text{ cm/s}$
$d = 1.7 \text{ mm}$

$$d_1 = d_2 \frac{\alpha_1}{\alpha_2} \frac{S_{L_2}}{S_{L_1}}$$

$$\alpha \sim T_u \bar{T}^{0.75} P^{-1}$$

$$\alpha \sim \frac{1}{P}$$

$$d_1 = d_2 \left(\frac{P_2}{P_1}\right) \frac{S_{L_2}}{S_{L_1}}$$

$$= 1.7 \text{mm} \left(\frac{1 \text{atm}}{5 \text{atm}}\right) \left(\frac{43}{19.2}\right) = 0.76 \text{mm}$$

$$Re = \frac{\rho_u \, d \, S_L}{\mu}$$ assume air prop.

$$= 61.5$$

Flammability Limit Problem

Tuesday, October 24, 2017 10:48 AM

A full propane (C_3H_8) cylinder from a camp stove leaks its contents of 1.02 lb (0.464 kg) into a 12' x 14' x 8' (3.66 m x 4.27 m x 2.44 m) room at 20 C and 1 atm. After a long time, the fuel gas and the room air are well mixed. Will the room go boom in the event of a spark?

$R_u = 0.08206$ atm-m^3/kmol-K
$MW_{propane} = 44.094$ kg/kmol
$MW_{air} = 28.85$ kg/kmol

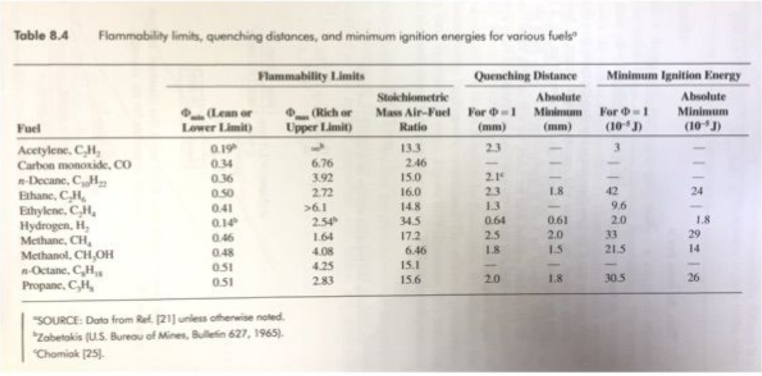


Table 8.4 Flammability limits, quenching distances, and minimum ignition energies for various fuels[a]

	Flammability Limits			Quenching Distance		Minimum Ignition Energy	
Fuel	Φ_{min} (Lean or Lower Limit)	Φ_{max} (Rich or Upper Limit)	Stoichiometric Mass Air–Fuel Ratio	For $\Phi = 1$ (mm)	Absolute Minimum (mm)	For $\Phi = 1$ (10^{-5} J)	Absolute Minimum (10^{-5} J)
Acetylene, C_2H_2	0.19[b]	∞[b]	13.3	2.3	—	3	—
Carbon monoxide, CO	0.34	6.76	2.46	—	—	—	—
n-Decane, $C_{10}H_{22}$	0.36	3.92	15.0	2.1[c]	—	—	—
Ethane, C_2H_6	0.50	2.72	16.0	2.3	1.8	42	24
Ethylene, C_2H_4	0.41	>6.1	14.8	1.3	—	9.6	—
Hydrogen, H_2	0.14[b]	2.54[b]	34.5	0.64	0.61	2.0	1.8
Methane, CH_4	0.46	1.64	17.2	2.5	2.0	33	29
Methanol, CH_3OH	0.48	4.08	6.46	1.8	1.5	21.5	14
n-Octane, C_8H_{18}	0.51	4.25	15.1	—	—	—	—
Propane, C_3H_8	0.51	2.83	15.6	2.0	1.8	30.5	26

[a] SOURCE: Data from Ref. [21] unless otherwise noted.
[b] Zabetakis (U.S. Bureau of Mines, Bulletin 627, 1965).
[c] Chomiak [25].

$X_F = \frac{\text{[illegible]}}{P}$

$$P_F = \frac{n R T}{V} = \frac{m(R_u/MW_F)T}{V}$$

$$= \frac{(0.464)\left(\frac{0.08206}{44.094}\right)293}{3.66(4.27)(2.44)}$$

$$= 0.00663 \text{ atm}$$

$$X_F = \frac{P_F}{P} = 0.00663$$

$$X_{air} = 1 - X_F = .99337$$

$$\phi = \frac{(F/O_2)_{act}}{(F/O_2)_{stoic}} = \frac{.00663/.21(.99337)}{1/5}$$

$$C_3H_8 \rightarrow 3CO_2 + 4H_2O$$

$$3 \quad +2 \rightarrow 5$$

$$\boxed{\phi = 0.159}$$