Spreading Angle Problem

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A jet of ethylene (C_2H_4) exits a 10-mm diameter nozzle into still air at 300 K and 1 atm. Compare the spreading angles and axial locations where the jet centerline mass fraction drops to the stoichiometric value for initial jet velocities of 10 cm/s and 1 cm/s.

$\mu_{C2H4,300K}$ = 102.3 x 10^{-7} N-s/m^2
R_u = 0.08206 atm-m^3/kmol-K
$MW_{ethylene}$ = 28.05 kg/kmol
MW_{air} = 28.85 kg/kmol

$$\rho = \frac{P}{(R_u/MW)T} = \frac{1\,atm}{(0.08206\ \frac{atm\,m^3}{kmol\,K})/(28.05\ \frac{kg}{kmol})\ (300K)}$$

$$= 1.14\ kg/m^3$$

Case 1: V_e = 10 cm/s

$$Re_{j_1} = \frac{\rho V_e R}{\mu} = \frac{(1.14\,kg/m^3)(0.1\,m/s)(0.005m)}{102.3 \times 10^{-7}\ Ns/m^2}$$

$$= 55.7$$

Case 2: V_e = 1 cm/s

$$Re_{j_2} = 5.57$$

Spreading angle:

$$\alpha = \tan^{-1}[2.97/Re_j]$$

Case 1: $\alpha = 3.05°$
2: $\alpha = 28.1°$

$$C_2H_4 + xO_2 \rightarrow 2CO_2 + 3H_2O$$

$$x = 3$$

$$Y_{F,stoic} = \frac{m_F}{m_F + m_{air}} = \frac{(1)\,MW_F}{(1)\,MW_F + (3 + 3(\frac{79}{21}))MW_{air}}$$

$$= 0.0637$$

$$Y_{F,0} = 0.375\,Re_j\,\left(\frac{x}{R}\right)^{-1}$$

$$x = \frac{0.375\,Re_j\,R}{Y_{F,0}}$$

Case 1: $Re_j = 55.7$

$$x = \frac{0.375\,(55.7)(0.005\,m)}{}$$

0.0637

= 1.64 m

Case 2: $K_{ej} = 5.57$

$x = 0.164$ m

Nozzle Exit Radius

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Using case II (v_e = 1.0 cm/s, R = 5 mm) from the previous problem as the base case, determine what nozzle exit radius is required to maintain the same flowrate if the exit velocity is increased by a factor of 10 to 10 cm/s. Also, determine the axial location for $Y_{F,0} = Y_{F,stoic}$ for this condition and compare to the base case.

$$Q = \text{const}$$

$$Q_{orig} = V_{e_{II}} \pi R_{II}^2 = 0.01 \, m/s \; \pi (0.005 m)^2$$
$$= 7.854 \times 10^{-7} \, m^3/s$$

$$Q = V_{e\,new} \pi R_{new}^2$$

$$R_{new} = \left(\frac{Q}{0.10 \, m/s \; \pi} \right)^{1/2}$$
$$= 0.00158 \, m$$
$$\approx 1.58 \, mm$$

$$Re_j = \frac{\rho V_e R}{\mu} = \frac{1.14 \, (0.1 \, m/s)(0.00158)}{102.3 \times 10^{-7}}$$
$$= 17.6$$

$$X = \left(\frac{0.375 \, Re_j}{Y_{F,stoic}} \right) R = \frac{0.375 \, (17.6)(0.00158 m)}{0.0637}$$
$$= \boxed{0.164 m}$$