Republic of Iraq
Ministry of Higher Education
and Scientific Research
Al-Mustaqbal University College
Chemical Engineering and Petroleum Industries Department

Subject: Combustion engineering

2nd Class

Lecture two

Diffusion Flames

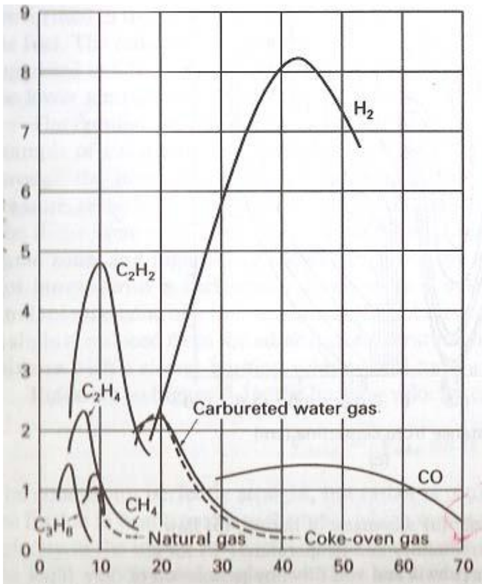
Diffusion flames take place when the sources of fuel and oxidizer are physically separate so that the energy release is limited primarily by the mixing process .There is no fundamental flame speed as in the case of premixed flames . Diffusion flames occur with flowing gases ,with vaporization of liquid fuels ,and with devolatilization of solid fuels . A candle flames is an example of a diffusion flames .Wax is melted , flows up the wick and vaporized . Air flows upward due to natural convection .The reaction zone is between the air and the fuel zones Air diffuses inward and fuel diffuse outward .In hydrocarbon flames , soot particles are produced giving rise to luminosity.

Laminar premixed flames

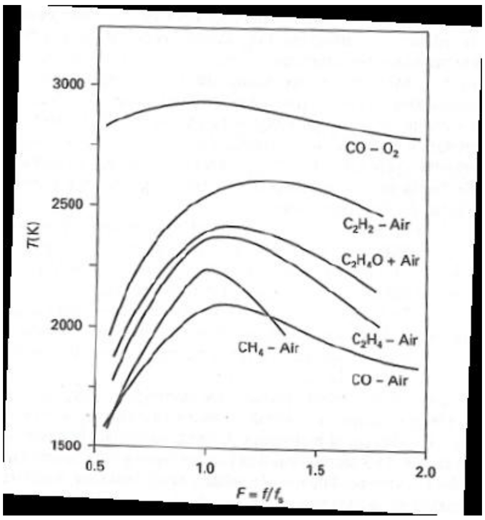
A combustion reaction started at a local heat source in a quiescent fuel-air mixture at ambient conditions will propagate as a laminar flame .chemical reaction take place in a relatively thin zone ,and the flame moves at a fairly low velocity .For stoichiometric hydrocarbon mixtures in ambient air the flame is approximately 1mm thick and moves at about (0.5 m/s).The pressure drop through the flame is very small (1Pa),and the temperature in the reaction zone is high (2200-2600 k).

Effect of stoichiometry on laminar burning velocity .

The effect of fuel concentration on the laminar burning velocity is shown in figure 1 for various fuels .it can seen that the laminar burning velocity for a particular fuel can vary by a factor **3** depending on the fuel/air ratio. The rich and lean limits of flammability are also shown in this figure laminar flames will not occur above or below these limits .Hydrogen has the highest velocity and widest limits of flammability while methane has the lowest burning velocity and the narrowest limits. The maximum burning velocities are found just to the rich side of stoichiometric .The fame temperature is highest near the stoichiometric and the lowest near the flammability limits figure 2.Higher laminar burning velocity is associated with a higher flame temperature The effect of nonreactive additives such as nitrogen or argon is to reduce the flame temperature and the laminar burning velocity .The most common diluents addition is product of combustion for example in power plants a fraction of the combustion products are sometimes recirculated with the inlet air to reduce the amount of No produced by decreasing the flame temperature. similarly in internal combustion engines a fraction of the residual products from the previous cycle mix with the new charge Other additives may react directly for example is the addition of small amounts of water(0.23%)to a CO-O2 mixture which increases the burning velocity by a factor of 8 .this is due to the formation of OH radical. .



Fig(1)The effect of fuel concentration on the laminar burning velocity

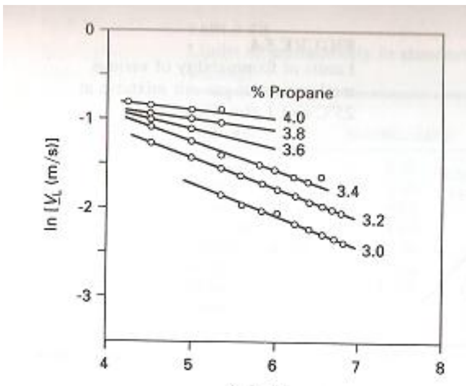


fig(2)Flame temp as a function of equivalence

Effect of reactant pressure and temperature on laminar burning velocity

For each premixed fuel-air mixture there is a characteristic laminar burning velocity .The burning velocity is defined as the flame relative to the unburned reactants The laminar burning velocity depends on fuel type fuel-air mixture ratio and initial temperature and pressure of the reactants . For slow burning mixtures (VL<0.6 m/s)the burning velocity decreases with increasing pressure . the observed pressure dependence can be expressed as a power law **,**(VL=a$\boldsymbol{p}^{ß}$)**,** where **p** is the pressure in atmospheres and **ß** varies from(0 to –0.5) for example , the burning velocities for propane – air mixtures at various pressures are shown in figure 3 for fast –burning mixtures (VL>0.6 m/s)**,** the value of **ß** either zero or slightly positive . increased pressure increases the flame temperature because there is less dissociation , and hence the burning velocity however , less dissociation means less active radicals are available to diffuse upstream to enhance flame propagation . both effects are important .

The burning velocity increases with the temperature of the reactants , provided the reactants do not partially react prior to the flame passage . The observed temperature dependence can also be expressed as a power law . and the burning velocity increases as the second or third power of the absolute temperature. for example , the maximum burning velocity for propane-air goes from **40cm/s** to **140 cm/s** as the reactant temperature is increases from 300K to 617 K .



Ln[p(Kpa)]

Fig(3) Influence of pressure on laminar burning velocity

Structure of CH4-Air flame

The structure of a premixed flame in fig (5)shows the temperature distribution and selected species mole fraction profiles (the principal C-containing CH4,CO,and CO2) through a1-atm ,stoichiometric , CH4-Air flame .Here we see the disappearance of the fuel, the appearance of the intermediate species CO and burnout of the CO to form CO2 .the CO concentration has its peak value at approximately the same location where the CH4 concentration goes to zero , whereas the CO2 concentration at first lags the CO concentration but the continues to rise as the CO is oxidized .Figure (6) shows that C-intermediate species CH3,CH2O AND HCO , are produced and destroyed in a narrow interval (0.4-1.1mm).

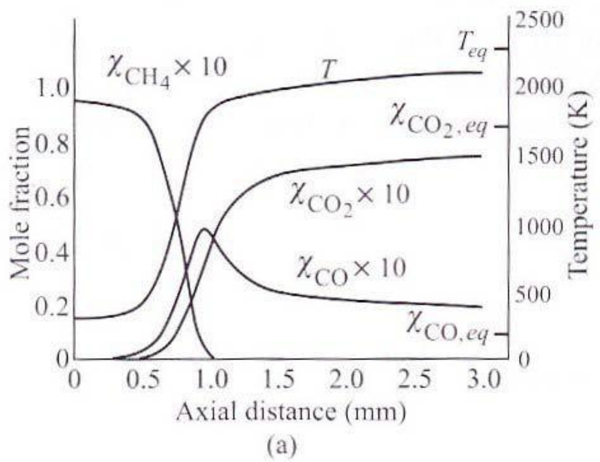
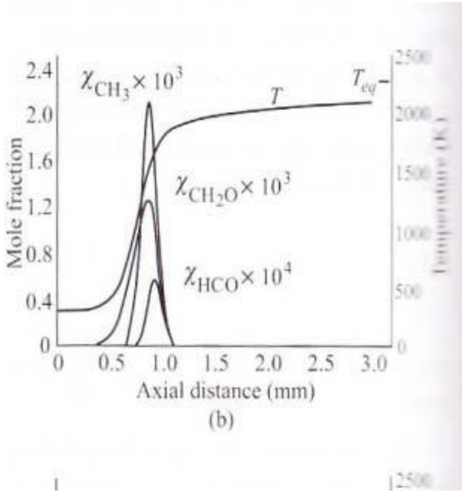
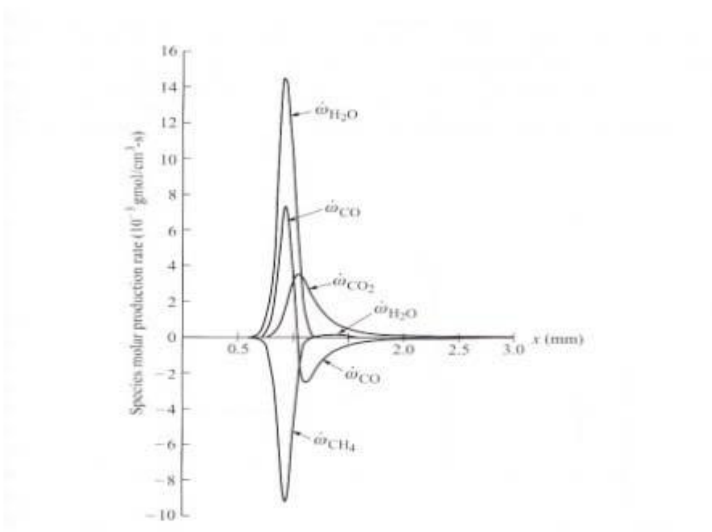


fig (5)



Fig(6)

Figure (7) provides additional insight into the CH4---CO---CO2 sequence by showing the local molar production (destruction) rates for these species. We see that the peak fuel destruction rate nominally corresponds with the peak CO production rate and the CO2 production rate initially lags that of CO .Even before the location where is no longer any CH4 to produce additional CO , the net CO production rate becomes negative ,I,e., CO is destroyed .The maximum rate of CO destruction occurs just downstream of the peak CO2 production rate .The bulk of the chemical activity is contained in an interval extending from about 0.5 mm to 1.5 mm .



Fig(7)

FLAME SPEED CORRELATIONS FOR SELECTED FUELS

Metghalchi and Keek experimentally determined laminar flame for various fuel-air mixtures over a range of temperatures and pressures typical of conditions associated with reciprocating internal combustion engines and gas-turbine combustors.

$$S_L = S_{L,\mathrm{ref}}\left(\frac{T_u}{T_{u,\mathrm{ref}}}\right)^{\gamma}\left(\frac{P}{P_{\mathrm{ref}}}\right)^{\beta}(1-2.1Y_{\mathrm{dil}}), \qquad (1)$$

For $Tu > 350$ K . The subscript ref refers to reference conditions defined by Tu,ref.r =289K and P =1 atm .

$$S_{L,\mathrm{ref}} = B_M + B_2(\Phi-\Phi_M)^2 \qquad (2)$$

Where the constants BM, $B2$, and ΦM depend on fuel type and are given in table 1 The temperature and pressure exponents, γ and β, are functions of the equivalence ratio, expressed as

$$\gamma = 2.18 - 0.8(\Phi - 1)$$

$$\beta = -0.16 + 0.22(\Phi - 1).$$

The term Y_{dil} is the mass fraction of diluents present in the air-fuel mixture. Recirculation of exhaust or flue gases is a common technique used to control oxides of nitrogen in many combustion systems and in internal combustion engines, residual combustion products mix with the incoming charge under most operating conditions.

Table 1 values for BM, $B2$, and ΦM

Fuel	Φ_M	B_M cm/s	B_2 cm/s
Methanol	1.11	36.92	-140.51
Propane	1.08	34.22	-138.65
Isooctane	1.13	26.32	-84.72
RMFD-303	1.13	27.58	-78.34