1 Introduction

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MEECH 6720: Combustion

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noticed soot coming out of the exhaust of Diesel engines; the combustion process in a Diesel involves the diffusion flame. The combustion process is a reaction between the fuel and air. The heat released during combustion is used to raise the temperature of the air, which in turn aids in the combustion process. This process is a diffusion flame because the fuel and air are mixed by diffusion, not by convection or other means.

Both the diffusion and combustion zones will be complex regions containing various chemical reactions. The diffusion zone is the region where the fuel and air are first mixed by diffusion. The combustion zone is the region where the fuel and air are further mixed to form a flame. The flame is the region where the chemical reactions of combustion occur. The flame is a region of high temperature and pressure, and it is responsible for the production of the heat and work that are released during combustion.

The diffusion flame is a complex system that involves a variety of chemical reactions. The most important of these reactions are the formation of carbon monoxide and carbon dioxide. These reactions occur when the fuel and air are mixed, and they are responsible for the production of the heat and work that are released during combustion. The diffusion flame is a complex system that involves a variety of chemical reactions. The most important of these reactions are the formation of carbon monoxide and carbon dioxide. These reactions occur when the fuel and air are mixed, and they are responsible for the production of the heat and work that are released during combustion.
time it takes oxidizer to diffuse to the fuel). During this time, the fuel has traveled from the burner exit to the flame tip at a speed of

\[ \frac{\Delta z}{\bar{T}} \approx \frac{d}{\bar{D}} \]

This is not the case for a slot burner. A slot burner on a circular port burner is not a physical model, but rather, it is an idealization of a slot burner, where the fuel flow rate and velocity of the boundary layer are.

**Buoyancy-Controlled Laminar Flames**

In many (if not most) small-scale jet diffusion flames, the flow field in and about the flame is controlled not by the momentum of the jet, but rather by buoyant acceleration of the gases. Flames, as you know, are hot, and the density differences between the hot gases and the cooler surrounding gases create buoyancy-induced flows.

In a buoyant flame, the axial velocity will accelerate due to the buoyancy effect and this will reduce the residence time in the flame. However, the flame thickness will also decrease as the flow accelerates. This is a result of a continuity (or mass conservation) principle. The volume of hot gases above the burner would be roughly constant with height, and for a circular port burner, where \( R_b \) and \( V_b \) are the radius and velocity of the buoyant flame, there

\[ A_{H \nu} \approx A_{B \nu} \approx 0 \]

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**Flame Height Correlations**

Turns devotes a few pages to the correlations for flame height of laminar jet diffusion flames formed on various types of ports (circular, square, slot). For the circular and square formulas, the flame height does not depend on whether the flow is momentum or buoyancy controlled. The correlation for the slot burner is different; a separate formula is given for momentum and buoyancy controlled conditions. The key factor (or dilemma) in predicting flame height for a laminar diffusion flame from a slot burner is that the appropriate correlation formula (momentum or buoyancy-controlled) depends on \( Fr \), yet \( Fr \) depends on \( L_f \). Therefore, to calculate the flame height, one must begin with the appropriate correlation and then derive the flame height from a slot burner is a circular port burner, then

\[ L_f = 1330 \left( \frac{Q_F}{T_1} \right) \left( \frac{T_1 - T_F}{1 + \frac{S}{L_f}} \right) \]

It is important to note that the quantities and units used in this correlation are

\[ \frac{(S/L) + 1}{(S/L + L/\bar{D})} \]

where \( R_b \) and \( V_b \) are the radius and velocity of the buoyant flame.

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The total volumetric ow rate of the jet. However, the fuel in the jet can be diluted with an inert gas, or it may contain some primary aeration (discussed below). In general, \( Q_F \) would be

\[
\frac{(S/F)_{\infty}}{(1/F)} \tilde{Q} = \bar{Q}_\tau
\]

where \( S \) is the value of \( S \) for a pure fuel. With no primary aeration, the total volumetric ow rate is

\[
\frac{1 + d\Phi/2\pi dS}{(d\Phi/1 - 1)2\pi dS} = S
\]

For this case, it turns out that

In a gas jet reaction (e.g., burning an unburned fuel), the heat released in the reaction is released to the surrounding air. The heat released in the reaction is then

\[
\text{Heat released} = S = \text{LHV} = \frac{315}{5} = 63 \text{kJ/kg}
\]

From an energy balance,

\[
\text{Heat released} = \text{Energy input} - \text{Energy output}
\]

or

\[
Q_F = \frac{1}{2} \tilde{Q} \text{ m3/s} = 15 \text{ cm}^3/s
\]

Now check to see if the ow (for pure fuel) is laminar. We don't have a value for viscosity for methane, so use air values as a rst approximation. From Appendix C, 300 K:

\[
\nu = 15.9 \times 10^{-6} \text{ m}^2/s
\]


\[
\text{Re} = \frac{VD}{\nu} = \frac{D^2V}{\nu} = 1.32 \times 10^5
\]

This ow will certainly be turbulent.

The flame height correlation for the circular burner is

\[
L_f = 1330 \tilde{Q}^{1/2} (\frac{T_1}{T_\Phi}) = 1330 \tilde{Q}^{1/2} (\frac{T_1}{T_\Phi}) \ln(1 + 1/S) = 1330 \tilde{Q}^{1/2} (\frac{T_1}{T_\Phi}) \ln(1 + 1/S)
\]

For pure fuel (methane), \( S = 2/4.76 = 9/52 \). Also, \( T_\Phi = T_1 = 298\text{K} \). So

\[
L_{f,\text{pure}} = 1330 \times (\frac{1}{53} \times 10^{-5})^{1/2} \ln(1 + 1/9) = 0.203 \text{m} = 20.3\text{cm}
\]

If the jet is now diluted with an inert substance (say \( N_2 \)) resulting in

\[
\frac{1}{\tilde{Q}^{1/2}} = \frac{1}{\text{m3/s}}
\]

then the heat released in the reaction is

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The point of primary aeration in diffusion flames is to shorten the flame length and also to reduce the formation of soot particles (which result in a yellow flame). The amount of formation of soot particles is shorter the flame length and also to reduce the formation of soot particles. The point of primary aeration is to shorten the flame length and also to reduce the formation of soot particles.
This is a fairly tall name. Now explore the effect of aeration on the name. We use the same formula for $L_f$, with the same $Q_F$, yet $S$ is now given by

$$S = \frac{1 + \frac{\Phi}{72} \cdot 6}{(\frac{\Phi}{1 + t}) \cdot 72 \cdot 6}$$

MatLab was used to generate a plot, and the plot is given below. This is a fairly tall flame. Now explore the effect of aeration on the flame. Generally enhance the transport of heat, mass, and momentum. Because in general the eddies that are formed in a turbulent flow field will Muller. Therefore, become influenced. We'll cover this influence in more detail after the course. But for now we can only write a quick rule of thumb. A higher primary aeration level will enhance the flame is increased for a fixed fuel port area, the flame height. As the plot indicates, primary aeration has a huge effect on the flame height. Using primary aeration, we can generate much smaller flames while keeping the same heating load and still retain the safety advantages. As long as the primary aeration level is below the flashback limit, the flame could not flash back through the burner. The eddy dissipation model would not flash back through the burner. While keeping the same heating load and still retain the safety advantages. - As the plot indicates, primary aeration has a huge effect on the flame height.
The Coupling Function

The most troubling and difficult part of Eqs. (8) and (9) are the reaction rate terms. Recall that in Eqs. (8) and (9) the reaction rate term $\phi$ is a function of temperature and fuel and oxidizer concentrations (or mass fractions). To predict the rate, we need to know the corresponding conservation equation for the chemical species (in this case, the reaction rate will be a function of temperature and fuel and oxidizer concentrations). The reaction rate will be zero except for regions where the reaction is actually occurring (i.e., the flame). Otherwise, the reaction rate is zero except for regions where the reaction is actually occurring. Would be zero except for regions where the reaction is actually occurring. In particular, the reaction rate would be zero everywhere except in the reaction zone. The reaction rate term $\phi$ would be a function of temperature and fuel and oxidizer concentrations, with subscripts representing the species.

There is a way to remove the reaction rate term from the equations. To do this, we need an assumption regarding mass and heat diffusion.

In particular, we assume that $\phi = 0$, where $\phi$ is the reaction rate. If we do this, we are making an assumption regarding mass and heat diffusion. This is a way to remove the reaction term from the equation – there is no way to remove the reaction term from the equation.

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The Lewis number is a ratio of characteristic mass diffusion and thermal (heat) diffusion times; it is analogous to the Prandtl number, which is a measure of heat and momentum diffusion times.

The Lewis number is defined as

\[ \text{Le} = \frac{D}{\alpha} \]

where \( D \) is the characteristic mass diffusion times, and \( \alpha \) is the characteristic thermal diffusion times.

For most gases, \( \text{Le} \approx 1 \). The Lewis number is often referred to as the Prandtl number when diffusion times are considered.
Application to a Slot Burner

Fig. 2: Slot burner configuration

The analysis in simplified if we make the variables in the problem dimensionless.

\[ \frac{x}{L} = \frac{\theta}{\Delta} \]

These substitutions in Eq. (16) become:

\[ \frac{\Delta}{\theta} = \frac{\theta}{\Delta} \]

The dependent variable in Eq. (17) is also dimensionless. With:

\[ \frac{T}{\theta} = \frac{\theta}{\Delta} \]

We now have a strategy to map out the position of the flame. We first

\[ a = \frac{\theta}{\Delta} \]

0 \leftarrow \frac{\theta}{\Delta} = \frac{\theta}{\Delta} \]

Since in slot burner configuration, there are no oxidizer mass fractions at in slot burner configuration. This is because, at the flame:

\[ \frac{\theta}{\Delta} = 0 \]

This approximation is then valid when the fuel and oxidizer react at the flame (and as they both go to zero) they are

\[ \frac{\theta}{\Delta} \]

And from there, the flame is the unique mass fraction of oxygen is zero. Which we solve Eq. (16) with:

\[ \frac{\theta}{\Delta} \]

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This approximation is then valid when the fuel and oxidizer react at the flame (and as they both go to zero) they are

\[ \frac{\theta}{\Delta} \]
where $L_b$ and $L_d$ are the widths of the fuel port and burner (see Fig. 2).

We also need boundary conditions along the $x=0$ surface (the symmetry line) and $x=L$ (the outer wall of the burner). There can be no mass transfer across these surfaces, so the derivative of the mass fraction $f$ with respect to $x$ at these surfaces must be zero. This is analogous to an adiabatic boundary condition in heat transfer.

For stoichiometric conditions, the ratio of the oxygen and fuel fluxes would be $\frac{v_{O_2}}{v_F} = \frac{L}{L_b}$, while for non-stoichiometric conditions, the ratio would be $\frac{v_{O_2}}{v_F} = \frac{L}{L_d}$.

\[ \frac{\partial f}{\partial x} = 0 \text{ at } x=0, x=L \]

We also need boundary conditions on the fuel side and air side of the burner. These can be written as:

On the fuel side ($f_{O_2} = 0$):
\[ f_{O_2} = 0 \text{ at } x=0, x=L \]

On the air side ($f_{O_2} = 1$):
\[ f_{O_2} = 1 \text{ at } x=0, x=L \]

In the plot on the left, the air supply is greater than the stoichiometric amount, producing an over-ventilated flame. On the right, the air supply is less than the stoichiometric amount, producing an under-ventilated flame. For this particular burner model, whether a flame is over or under-ventilated depends on the fuel port width $L_b$. The mass flux rates of fuel and oxygen (per unit length of the burner in and out of the paper) would be

\[ \frac{\partial f}{\partial x} = 0 \text{ at } x=0, x=L \]

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The color bars correspond to various levels of $f_{O_2}$; they are not meant to be quantitative as much as qualitative.
The two plots, corresponding to overventilated and underventilated conditions, depict the temperature at the flame front compared to the adiabatic flame temperature, as predicted by a constant specific heat analysis. If the temperature at the flame front is less than the adiabatic flame temperature, the flame is overventilated. If the temperature at the flame front is equal to the adiabatic flame temperature, the flame is a precise stoichiometric case of the above criteria; a diffusion flame corresponding to the undissolved fuel in an unconfined oxidizer is shown. If the temperature at the flame front is greater than the adiabatic flame temperature, the flame is underventilated. For the special case of the above criteria equaling $\frac{\Delta H_f}{T}$, the flame front would not form a tip; it would extend straight up into the surrounding atmosphere and would eventually be extinguished once all the fuel is consumed. The temperature at the flame front will correspond to the adiabatic flame temperature, as predicted by a constant specific heat analysis.

The temperature at the flame front is given by:

$$T_{flame} = T_{adiabatic}$$

for overventilated conditions.

For underventilated conditions, the temperature at the flame front is:

$$T_{flame} = T_{adiabatic} \left(1 - \frac{\alpha_f}{\alpha_T} \right)$$

where $\alpha_f$ is the stoichiometric air-fuel ratio and $\alpha_T$ is the actual air-fuel ratio at the flame front.