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2. COMBUSTION IN NATURAL FIRES

Learning Objectives

Upon completion of this chapter, you should be able to:

- Identify different forms of natural fire: diffusion flames, smoldering, and premixed flames.
- Explain how a candle flame, a basic diffusion flame, works.
- Recite quantitative aspects of natural fire
- Describe the processes leading to ignition and spontaneous ignition.

Summary

Natural fire can be divided into three types of combustion

1. Diffusion flames.
2. Premixed flames,
3. Smoldering,

Combustion to a flame or smoldering requires an ignition process. Energy must be put into the reactants to achieve a thermally runaway process and a sudden jump in temperature to a combustion state. This jump is caused by fact that the energy production rate of the reaction depends on temperature. Laminar flames in air can achieve temperatures of about 2000 ºC, and a low of about 1300 ºC before extinction. Smoldering in air might occur as low as about 300 ºC. The temperature in a turbulent flame is practically represented by an average much lower that the laminar fluctuating flames in its structure.

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The adiabatic flame temperatures in air for many hydrocarbons are about 2000 ºC with some exceptions. This can be explained by the nearly constant energy release of oxygen, about 13 kJ/g.

A diffusion flame has fuel and oxygen on either side of the flame while in a premixed flame the two are mixed before combustion. A candle flame is representative of a diffusion flame. Soot and other incomplete products of combustion occur on the fuel side of the flame. Smoldering also requires the diffusion of air to the solid fuel.

Smoldering is a slow propagation process at speeds of 0.01 cm/s at most. Laminar premixed flame speeds in air can range from about 20 to 100 cm/s, with turbulent speeds increasing by up to 100 times. Detonation speeds can achieve 2000 m/s.

Spontaneous combustion or auto-ignition occurs because the fuel undergoes an exothermic reaction (generating chemical energy) that cannot be sufficiently cooled. As a result, the reaction accelerates and leads to either flaming or smoldering combustion. Spontaneous ignition can result by decomposition or by oxidation, as in the drying of linseed oil on cotton. It can take hours or days to develop ignition.

Review Questions

1. What role does temperature play in combustion?

Temperature is key because a sufficiently high enough temperature insure the existence of a flame given fuel and oxygen.

2. Under what circumstances can a premixed flame ignite and propagate?

There needs to be a flammable mixture and a sufficient ignition source.

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3. How does a diffusion flame begin?

It always starts with a premixed flame.

4. Explain the role of airflow in smoldering.

The diffusion of air, enhanced by wind flow, supplies the oxygen to the reacting solid.

5. Why might spontaneous ignition take so long?

It occurs in a system that is exothermic in its oxidation reaction or in its decomposition. An array of such material is essentially insulated by itself. The process can lead to a rise in temperature in the reaction region. Eventually the temperature may reach a "runaway" condition and accelerate its rise to either smoldering or flaming.

True or False

1. Autoignition requires a pilot flame.

False, auto means self; it occurs by itself.

2. An oxy-acetylene torch is a diffusion flame.

False, it is a premixed flame.

3. A burning pool of gasoline is a diffusion flame.

True. Liquid evaporates and meets entraining air.

4. Charring is not likely during smoldering.

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False. Charring is almost synonymous with smoldering, as it would occur in surface oxidation.

5. Plastics cannot smolder.

False. Some plastics, as wood, smolder. Polyurethane foam in the presence of a fabric will smolder and char from a hot source.

6. Smoldering can occur in concealed spaces with very little air.

True. Know to occur in buried coalmines.

7. A flame must be 10 ft high to be turbulent.

False. About 1 ft could be sufficient to trigger turbulent flow.

8. Temperature plays a key role in determining if a flame can occur.

True. A minimum temperature is needed to sustain the flame reaction.

9. A canister of raw plastic material with insufficient anti-oxidants could lead to spontaneous ignition.

True. The lack of anti-oxidants can promote oxidation.

10. Most hydrocarbon fuels have about the same flame temperature burning in air.

True. Investigate the adiabatic flame temperatures of many fuel to justify this answer.

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Activities

1. Conduct and discuss the candle experiments described in this chapter.

A good resource is the Candle video from cfitrainer.net.

2. Measure the velocity of a smoldering process, e.g., a cigarette. See how air speed might change the smoldering rate.

This can be observed and easily studied.

3. Put linseed oil soaked (not too wet) cotton rags in a cardboard box about 1 ft^3. Place in a safe place for doing fire tests and let sit for several hours. Explain the results. Measure the center temperature if possible.

Don't walk away from this experiment and conduct it in a place that will not be a hazard if flaming or smoldering ignition occurs. It can take several hours.

4. Compare the different flames produced by a Bunsen burner by regulating the air vents. Can you blow the flame off by increasing the flow too high? Can the premixed flame, with the vents open, be extinguished as the fuel flow rate is decreased? With the vents closed, as you increase the fuel flow rate does the flame height level out?

Do this with care, as loose garment with an open flame can be dangerous.

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