Course Learning Outcomes for Unit IV

Upon completion of this unit, students should be able to:

1. Explain the physical and chemical properties of fire.
   1.1 Define the categorization of flames.
   1.2 Describe laminar and turbulent flames
   1.3 Categorize the flash point, fire point, and autoignition temperature of a flammable liquid.

4. Describe and apply the process of burning.
   4.1 Compare the flammability limits of burning velocity.
   4.2 Evaluate the three zones of the plume of a fire burning in the relationship of air entrainment into the flame.

5. Define and use basic terms and concepts associated with the chemistry and dynamics
   5.1 Analyze the minimum rate of heat release that leads to a flashover.
   5.2 Compare the smoke flow through different types of buildings.

Reading Assignment

Chapter 7:
Fire Characteristics: Gaseous Combustibles

Chapter 8:
Fire Characteristics: Liquid Combustibles

Chapter 12:
Movement of Fire Gases

Unit Lesson

Understanding the flame phenomena is critical for the safety of firefighters. However, is it important to understand diffusion of flame spread across a combustible item? How does that relate to firefighters making entry into a structure? Why is it important to understand the categorization of flames from Bunsen burners, Porous-plate flat-flame burners, or any other type of burner using natural gas or liquefied petroleum gas? Why is it important to understand fuel being diffused with air? Shackelford (2009) stated, “The diffusive flaming process is characterized by flames, generally yellow in nature as the burning process is not complete” (p. 58). According to Shackelford the appearance is as though the fuel to air ratio is incorrect. He claimed, “It is the most common type of flaming that will be encountered by firefighters” (p. 58) and the yellow flame suggests carbon monoxide being formed. Corbett and Pharr (2011) support Shackelford, suggesting the color of the flame is characterized by the percentage of oxygen available for combustion and fuel composition. Will the entrainment of more air into the flame improve combustion? Is there another element that needs to be considered?

Gann and Friedman (2015) state that, for combustion to occur, the air mixture and the fuel mixture must be within the flammable limits range of the material involved, which is indicated by the change in flame color. The authors continue by saying, “Flame types fall into the following categories: Premixed flames or diffusion flames; laminar flames or turbulent flames; stationary flames or propagating flames; subsonic flames (deflagrations) or supersonic flames (detonations)” (p. 96). The authors suggest there are other possible combinations of these categories. McCaffery (1979) claimed buoyancy diffusion flame as another type. He stated that buoyancy diffusion flame propagation is viewed as intermittent velocity of the plume or fluctuating of the flame. The graphic illustration below shows intermittent velocity of the plume from a fire in a chair and the three zones of the fire plume structure. Is this all there is to combustion?

Click [here] to access an interactive media file.

According to Corbett and Pharr (2011), flames are affected by "the heat release rate, the diameter of the burning fuel, and the mixing of the entrained air into the reaction zone [which] drives the pulsing structure along its perimeter and at the top of the flame plume" (p. 76). Gann and Friedman (2015) suggested that, in addition, there is the movement of fire gases as the result of gasification of the solid or liquid that is burning. The authors state, "When the molecular fragments leave the fuel surface, they have almost no momentum. They rise into the air above strictly due to buoyancy" (p. 213). In other words, looking at the graphic illustration, as the air is being entrained into the perimeter of the flame the air picks up molecular fragments that are being released from the chair through the pyrolysis process. In addition, there are many other factors that affect the fire development: the number of openings allowing air entrainment, the size or volume of the room or compartment the chair is in, the fire plume under the ceiling releasing thermal radiation, and the smoke flow from the burning chair. In fact, if there were no openings in the graphic illustration one of two things would begin to happen. According to Gann and Friedman (2015) the first thing to occur would be the release of heat causing:

> An increase in the pressure and temperature of the gases in the compartment, according to the ideal gas law. Ordinary construction materials can withstand a substantial increase in pressure if the pressure is applied evenly and gradually. However, windows can break in a fire because of stresses created when the viewable area of the glass is heated and expands more than the area shaded by the frame. (p. 217)

In this instance the room would be entrained with air and the fire will increase, building thermal layers of heated gases evenly throughout the fire compartment. The superheated gas layered through the structure begins to increase in temperature and the radiant heat from the fire heats all the combustible material in the room at, or near, its ignition temperature (IFSTA, 1998). Corbett and Pharr (2011) suggest this would increase the temperature and, as the temperature increased, the volume pressure would increase. The authors referred to this as the expansion of matter. If all the combustible material does not reach ignition temperature in the room this could result in a flameover with flames traveling across the ceiling. If all the combustible material reached ignition temperature then the entire room could ignite at once in a flashover.

The second thing that could happen, "if no rupture occurs, the oxygen in the compartment becomes depleted to the point that the combustion ceases" (Gann & Friedman, 2015, p. 217). As the material burns, the volume of smoke increases and flows across the ceiling in thermal layers. As layers build they bank down the walls being entrained back in to the flame of the chair burning. As this occurs the entrained air is depleted and the fire decays. The fire remains at this state until either air is entrained into the flame and heated gases or the heat is removed over a period of time and the fire becomes self-extinguished. However, if the compartment is still very hot and the decaying fire is diffused with air a backdraft will occur. Corbett and Pharr (2011) describe this as, "an example of fuels diffused in air and burning with rapid flame spread rates, which result in a pressure rise of explosive force" (p. 38) or, in other words, a backdraft.

> Points to Ponder
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> Units are doing live fire training in an acquired masonry structure. The fire room was a two-car garage that had been converted into a family room. The rough opening for the garage door had been replaced with masonry blocks and two fixed plate glass windows. Wood, cardboard and straw is being used as the fuel and the ignition source is a flare. The flames are fluctuating at first and build to a luminous flame producing more and more heat. As the heat begins to build a thermal layer forms and begins to bank down. The ignition temperature of all the material in the room increases. The pressure volume of the gases and heat in the room gradually increases to the point of breaking most of the single-pane windows. However, the fixed-plate glass window is not affected. Units make entry to the doorway and the outside vent is called.

What are the flame characteristics in the scenario? Is air being entrained into the perimeter of the flame in the scenario? What is the smoke movement? If the plate glass window is vented what will happen? If firefighters are making entry inside the room at the same time as the plate glass is vented what will happen?

In this unit you will evaluate flames being characterized as premixed or diffusion, laminar or turbulent, and stationary or propagating. The comparison of the reactions for the combustion of fuel molecules, chain propagating steps, chain branching steps, and chain termination steps will also be covered. You will analyze how the plume of a fire burning in the open can be depicted as containing three zones. You will explore the luminous zone; the intermittent zone where the average gas temperature and upward velocity are constant; and the buoyant plume where the temperature and velocity decreases with height. You will learn the filling of smoke in a compartment and smoke movement with openings or non-openings.

References

Corbett, G., & Pharr, J. (2011). *Fire dynamics*. Upper Saddle River, NJ: Pearson Education.

Gann, R., & Friedman, R. (2015). *Principles of fire behavior and combustion* (4th ed.). Burlington, MA: Jones & Bartlett:

International Fire Service Training Association (1998). *Essentials of Fire Fighting* (4th ed.). Stillwater, OK: Oklahoma State University Fire Protection Publications.

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McCaffrey, B. (1979, October). Purely buoyant diffusion flames: Some experimental results. *NBSIR,* 79-1910. Retrieved from http://fire.nist.gov/bfrlpubs/fire79/art001.html

Shackelford, R. (2009). *Fire behavior and combustion processes*. Clifton Park, NY: Delmar.

Suggested Reading

Five House Fire in Maple Ridge (full 40 minute version) https://www.youtube.com/watch?v=PDZtVTgTElY

This is a 40 minute video to show the filling of a fire compartment (houses) by smoke and then smoke flow from houses with an openings and heat release that leads a room to flashover and develop into fully involved.
Smoke movement modelled in FDS5
https://www.youtube.com/watch?v=cZOhXf2qvxM

This is a clip from a Discovery Channel video that was filmed at the Governors Island Experiments (FDNY) which held 18 controlled burns over a ten day period to “test” the application of science to firefighting. This clip features FDNY Chiefs as well as researchers. It can be found at:
http://watch.discoverychannel.ca/#clip784350

Learning Activities (Non-Graded)

Review What You Have Learned

The Challenging Questions at the end of Chapter 7, on page 115, will help you evaluate premixed flames and diffusion flames and why combustible gas-air mixtures are flammable in certain proportions and not flammable in other proportions.

Review What You Have Learned

The Challenging Questions at the end of Chapter 8, on page 129, will help you compare the three temperatures characterizing the ability to ignite a liquid. The flash point is the temperature at which piloted ignition occurs, but is not sustained and is the temperature at which the vapor pressure of the liquid equals the lower flammability limit. At the slightly higher fire point, the flame is sustained. The autoignition temperature is hundreds of kelvins higher and applies to unpiloted ignition.

Review What You Have Learned

The Challenging Questions at the end of Chapter 12, on page 222, will help you analyze how the plume of a fire burning in the open can be depicted as containing three zones. The lowest zone is luminous, and the gases accelerate upward. The flames in the middle zone are intermittent; the average gas temperature and upward velocity are constant. The upper zone is a nonluminous buoyant plume, and the temperature and velocity decrease with height.

These are non-graded activities, so you do not have to submit them. However, if you have difficulty or questions with the concepts involved, contact your instructor for additional discussion and/or explanation.