

Chapter Three – Fire Science

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A “chunk” of grease taken out of a restaurant exhaust system, lit with one match



Restaurant going up in smoke

Fire Science

Physics of Combustion

This chapter includes basic qualitative fire science topics that are essential in the analysis of fires particular to commercial kitchens. Our focus is primarily on fuel (natural gas, etc.), grease accumulations and common building construction materials. To appreciate the nature of fire, some important definitions must be understood.

NFPA 921 defines fire as “A rapid oxidation process, which is a chemical reaction resulting in the evolution of light and heat in varying intensities.” Fire is also defined¹ as an “uncontrolled combustion”. Controlled combustion occurs in a heating appliance such as a furnace, boiler, or range etc.; by contrast, uncontrolled combustion does not take place in an appliance designed for this purpose. With “uncontrolled combustion” the rate of fuel consumption and the heat generated are not controlled by a purposive mechanism.

Combustion is defined¹ as “A self-sustained, high-temperature oxidation reaction.” The NFPA 921 definition is “A chemical process of oxidation that occurs at a rate fast enough to produce heat and usually light in the form of either a glow or flame.”

Oxidation: current-day chemistry defines¹ it as “A chemical reaction in which a compound or a radical loses electrons.”

Fuels are known as substances which can readily lose an electron. NFPA 921 defines fuel as “A material that will maintain combustion under specific environmental conditions.” Charcoal may be the solid fuel used for cooking (controlled combustion) while the combustibles stored or left too close to the cooking appliance (i.e. a cardboard box may also be fuel as a result of the fire spread as uncontrolled burning). Likewise, natural gas may be the fuel for the deep fryer while the vegetable oil is the fuel for the fire.

In general, chemical reactions can either absorb or give off energy. Reactions that absorb energy are called endothermic reactions. Reactions that give off energy are called exothermic reactions, and the overall effect of combustion must manifest as an exothermic reaction. Fire is an exothermic chemical reaction that gives off energy in the form of heat and light. It is this energy that makes fire useful or destructive.

Reaction rates increase with increasing temperature, so the energy given off in an exothermic reaction can increase the reaction rate, resulting in the release of even more energy. This process can result in a phenomenon called “thermal runaway.”

Pyrolysis: The chemical degradation of a substance by the action of heat. NFPA 921 defines pyrolysis as “A process in which a material is decomposed or broken down, into simpler molecular compounds by the effects of heat alone: pyrolysis often precedes combustion.” In fire science, sometimes pyrolysis is used to refer to a stage of fire before flaming combustion has occurred. Pyrolysis can take place in a liquid, but typically with solids, the most relevant being wood.



Effects of heat on stainless steel kitchen components: (1) Because stainless steel is designed to resist ferrous corrosion/oxidation, when exposed to high heat stainless steel doesn't show the characteristic "rust" color as readily as do other ferrous materials, and (2) both photos show areas of higher local heat in the "clean burn" patterns, where the metal was too hot for soot to stick to it.

¹ Babrauskas, V., *Ignition Handbook*, Fire Science Publishers/Society of Fire Protection Engineers, Issaquah WA (2003).

Fire Tetrahedron

NFPA 921 defines fire as: “A rapid oxidation process, which is a chemical reaction resulting in the evolution of light and heat in varying intensities.”² For combustion, or fire, to occur there are several elements that must exist.

They are:

- Fuel – any substance that can undergo combustion
- Heat – energy above the minimum level necessary to release fuel vapors resulting in ignition
- Oxidizing Agent – in most cases, the oxygen available in the earth’s atmosphere

(These first three elements comprise the traditional fire triangle)

- Uninhibited chemical chain reaction – self-sustaining combustion that continues when sufficient heat from the fire radiates back to the fuel in the absence of the original ignition source

In today’s fire science literature, these four elements are represented in the form of the Fire Tetrahedron.

What this means is, if all four elements are present in sufficient measure, fire can occur. With the removal of one of the items, fire cannot be sustained. This is the basis for fire prevention practices and fire extinguishment concepts.

Fuel

In a kitchen environment the fuel can be the fuel gas supply, the food, the heat transfer medium (cooking oil), grease buildup, or combustible materials stored in the kitchen. Combustion can occur in liquid or solid fuels, in a region of vapors or pyrolysis³ products above the fuel surface, created by the heating of the fuel.

In kitchen exhaust systems, grease buildup will aid in sustaining a fire that reaches into the system. If not extinguished by the fire-extinguishing system, the amount of combustible fuel (grease) can affect the degree of damage sustained by the exhaust system and surrounding structure.

Heat

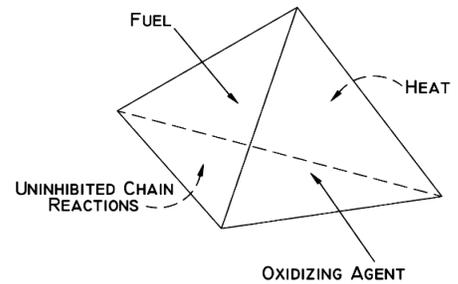
Commercial cooking equipment produces heat from a variety of sources; flaming combustion from the cooking appliances, plumes of heat rising above the appliances, or elevated temperatures from hot surfaces. These conditions exist in the normal cooking environment. Abnormal or elevated heat conditions can result in the uncontrolled ignition of cooking oil or grease.

Oxygen (Oxidizing Agent)

Oxygen is in abundant supply for combustion in any exhaust system whether or not the fan is on. Normal air contains 21% oxygen, and flaming combustion can occur at oxygen concentrations as low as 12 to 14%. Even in a tightly closed environment (a closed building) where the combustion progressively consumes oxygen, a destructive fire can occur.

Uninhibited Chemical Chain Reaction

This last element is necessary after ignition for the fire to be self-sustaining and spread through the fuel beyond the initial heat source. Chain reactions (which are an integral part of combustion chemistry) are what allow a flame to be established in accumulated grease around a commercial cooking appliance. Some extinguishing agents, such as dry chemical (usually sodium bicarbonate) and the halons, are effective, in part, because they break or inhibit the combustion chain reaction.



THE FIRE TETRAHEDRON

Courtesy of FIREPRO® Incorporated

² NFPA 921, Definitions

³ A process in which material is decomposed, or broken down into simpler molecular compounds by the effects of heat alone; pyrolysis often precedes combustion. (NFPA 921, Definitions)

Ignition of Solid and Liquid Fuels

Ignition is simply the initiation of self-sustaining combustion. Ignition can be further defined as smoldering or flaming. Smoldering sources of ignition in kitchen environments may be hot coals or glowing embers in solid fuel appliances. Flaming ignition sources could include a pilot light or flame from a gas appliance.

For solid and liquid fuels to be ignited, they must be in a gaseous or vapor⁴ state. The rate of heat transfer to the fuel must be greater than the sum of the heat losses from the fuel, if a fuel is to increase in temperature to produce ignitable vapors. For fuel to reach its ignition temperature⁵, the temperature of the heat source must be higher than the ignition temperature of the fuel. An exception to this is instances where spontaneous ignition occurs.

NFPA 921, Section 5.2.2.2, Phase Changes and Thermal Decomposition:

Thermal decomposition involves irreversible changes in the chemical structure of a material due to the effects of heat (pyrolysis). Thermal decomposition of a solid or liquid most often results in the production of gases.

Other points under NFPA 921, Section 5.5.2.3 are:

- High-density materials of the same type conduct heat energy away from the area of ignition more rapidly than low-density materials. With the same ignition source low-density foam plastic is easier to ignite than wood.
- The surface area to mass ratio has an effect on the quantity of energy needed for ignition. It is easier to ignite wood kindling than a log.
- The presence of a pilot flame results in ignition at lower temperatures compared to the absence of a pilot flame (there are a few exceptions to this)

Heat Transfer and Heat Flux

An integral part of every fire is the transfer of heat, both to the fuel (which is critical to continuity of the fire), and away from regions of combustion, whatever their type. The principles of heat transfer are relatively simple and are vital to the understanding of the fire itself. The rate at which heat is falling upon a surface (or passing through an area) is called the heat flux.⁶

Heat is transferred in three fundamental ways: (1) conduction, (2) convection, and (3) radiation. All of these methods play a part in fires. However, the relative importance of each will vary with the intensity and size of the fire, as well as the shape and content of the environmental system that is burning.



⁴ The gas phase of a substance, particularly of those that are normally liquids or solids at ordinary temperatures. (NFPA 921, Definitions)

⁵ Minimum temperature a substance should attain in order to ignite under specific test conditions. (NFPA 921, Definitions)

⁶ DeHaan, J. D., and Icove, D. J., *Kirk's Fire Investigation*, 7th ed., Brady/Prentice-Hall, Upper Saddle River NJ (2012).