



## WHA Characteristic Elements of Common Ignition Mechanisms

### **Particle Impact**

- Heat generated when small particles strike a material with sufficient velocity to ignite the particle and/or the material. Most efficient mechanism to directly ignite metals.
1. Particulate. Assume the presence of particles unless system is extremely clean or well filtered. Typical filtration levels for high-pressure GOX systems are nominally 10 microns (NASA RP 1113). Typical filtration levels for industrial systems are 30 to 100 mesh (~600 to 150 microns<sup>1</sup>, CGA G4.4).
  2. High velocities (~>100 ft/s)
    - Valves, orifices, and regulators
    - High  $\Delta P$  = high velocity
    - $\Delta P$  approximately 2:1 (or greater) = sonic velocity
    - $\Delta P$  approximately 3% across component = velocity > 150 ft/sec
  3. Impact point and residence time (Residence time increases dramatically with sudden changes in the direction of gas flow; therefore, the greater the angular change, the more efficient the target for particle impact. CGA G4.4 uses a radius to diameter ratio of 1.5 to discriminate between impingement and non-impingement on formed elbows, or efficient impact and non-efficient impact)
  4. Flammable particle and target (except for some metals like aluminum which can be ignited by impact from an inert particle).

*Example: A 90° elbow or Tee placed directly downstream of a flow control valve OR the seat and outlet portion of a throttling in-line globe valve.*

### **Adiabatic Compression**

- Heat generated when a gas is compressed from a low to a high pressure. Most efficient mechanism to directly ignite nonmetals.
1. Pressure ratio:  $T_f/T_i = [P_f/P_i]^{(n-1)/n}$ , where  $n = C_p/C_v = 1.4$  for oxygen
  2. Rapid pressurization
    - Ball valve, cylinder valves, plug valves

---

<sup>1</sup> As early as 1965 industrial oxygen suppliers recognized that particle impact and filtration were key elements of a safe oxygen system. W. E. Groves of the Union Carbide Corporation published a paper, "Safe Handling of Large Quantities of Gaseous Oxygen in Steel Pipelines", where he reported that in particle impact testing relevant to pipelines, "iron particles could be ignited only when composed of a full range of particle sizes from 0 to 40 microns". From the test data he concluded that, "It would be desirable at all times to use filters which would remove particles larger than 40 microns (350 mesh). Such filters, however, are not practical at present in large sizes." (due to expense). Consequently, the industrial gas industry filters typically with 30 to 100 mesh and also rigorously reduces gas velocities to avoid particle impact hazards.



3. Exposed flammable nonmetal close to dead end

*Example: A polymer-lined flex hose attached to a cylinder valve and a manifold isolation valve with no distance pieces implemented.*

**Flow Friction**

- Oxygen flows across the surface of, or impinges directly upon, a nonmetal in such a way that enough heat is generated within the nonmetal to cause ignition.
1. Higher pressure systems (>500 psi)
  2. Leak or “weeping” flow configuration
    - External leaks (seals)
    - Internal leaks (seats)
  3. Exposed flammable nonmetal in flow path
    - Chafed or abraded surface increases risk

*Example: An oxygen cylinder valve with a nonmetal seat that has been cycled extensively and is used in a throttling manner.*

**Galling and Friction**

- Heat generated by the rubbing of two or more parts together.
1. Two of more rubbing surfaces.
    - Metal-to-metal contact is generally most severe as it destroys protective oxide surfaces or coatings and exposes fresh metal.
  2. High speed and high loads more severe
    - Normal load/pressure x Rotational velocity/frequency (Pv product)
  3. One of the rubbing surfaces is flammable.

*Example: A reciprocating compressor with worn piston ring seals causing rubbing of the piston on the internal cylinder wall.*

**Promoted Ignition/Kindling Chain**

- Heat from the ignition and combustion of a more flammable material igniting a less flammable material, i.e., paper, twigs, and logs.
1. Contaminants present
    - Usually nonmetals, such as hydrocarbons and/or small polymers
  2. Ignition mechanism
    - Starts kindling chain
    - Adiabatic compression and flow friction common
  3. Flammable materials to kindle/propagate



*Example: hydrocarbon oil contaminates the inlet of a welding regulator causing ignition followed by burn out when the attached cylinder valve is opened.*

### **Static Discharge**

- Accumulated static charge on a nonconducting surface discharges with enough energy to ignite material receiving the discharge.

Not widely studied, but generally

1. Static charge buildup from flow or rubbing accumulates on a nonconducting surface
2. Discharge typically at a point source between materials of differing electrical potentials
3. Two charged surfaces are not as likely to arc unless one material is conductive
4. More severe in dry gas or dry environment

*Example: Large diameter ball valves with nonmetal upstream and downstream seats, where the ball/stem can become electrically isolated from the body and a charge differential develop between the ball and body from the ball rubbing against the large surface area nonmetal seat.*

### **Electrical Arc**

- Electrical arcing through ungrounded or short-circuited powered components causing ignition of a flammable material.
1. Ungrounded or short-circuited power source such as motor brushes, electrical control equipment, instrumentation, lighting, etc.
  2. Flammable materials capable of being ignited by the electrical arc or spark

*Examples: An insulated electrical heater element undergoing a short circuit arcing through its sheath to a combustible material, OR exposed wiring from electrical cables in an oxygen enriched compressor housing*

### **Mechanical Impact**

- Single or repeated impacts on a material with sufficient force to ignite it.
1. Single, large impact or repeated impact loading
  2. Nonmetal at point of impact. Generally, in laboratory testing this mechanism is only active in nonmetals, though aluminum, magnesium, and titanium alloys in thin cross-sections as well as some solders have been ignited experimentally. However, in these alloys, mechanical failure (which introduces additional ignition mechanisms) will likely precede or at minimum coincide with, mechanical impact ignitions in liquid oxygen (LOX).



3. Special caution for impact on certain materials in LOX: Porous hydrocarbon materials such as asphalt, wood, and leather, can become shock-sensitive in LOX and react explosively when impacted.

*Example: A high-pressure relief valve “chattering,” imparting repeated impacts on a nonmetal seat, leading to ignition of the seat, OR leather work glove soaked in LOX and exposed to impact of a wrench*

### **Resonance**

- Acoustic oscillations within resonant cavities that cause rapid temperature rise (more severe if particles are present).
1. Specially “tuned” resonance cavity. The requirements include a throttling device such as a nozzle, orifice, regulator, or valve directing a sonic gas jet into a cavity, or closed-end tube.
  2. Acoustic resonance phenomena, often audible. The distance between the throttling device and the closed end affects the frequency of acoustic oscillations in the cavity, similar to a pipe organ with a closed end, due to the interference of incident and reflecting sound waves. This distance also ultimately affects the temperature produced in the cavity. Higher harmonic frequencies have been shown to produce higher system temperatures. The resonant frequency has been shown to be a function of pipe diameter and pressure ratio.
  3. Flammable particulate or contaminant debris at closed end. Particulate or debris residing at the closed end of the cavity can self-ignite due to the high gas temperatures produced by this phenomenon, or they can vibrate, or resonate, and their collisions generate sufficient heat to self-ignite.

*Example: Resonance igniters for solid or liquid rocket fuel: Gaseous oxygen flows through a sonic nozzle and directly into a resonance cavity, heating the gas and solid or liquid fuel. When the gas reaches the auto-ignition temperature of the fuel, ignition occurs and a flame jet is emitted from the chamber.*

### **Thermal Ignition**

- Heating a material in an oxidizing atmosphere to a temperature sufficient to cause self-ignition (also known as spontaneous or autogenous ignition). In thermal ignition testing, the self-ignition temperature, or autogenous ignition temperature, is normally used to rate material compatibility with oxygen as well as evaluate a material’s ease of ignition. The ignition temperature of a given material is generally dependant on the effect of its thermal properties, including thermal conductivity, heat of oxidation, and thermal diffusivity, as well as other parameters such as geometry and environmental conditions.
1. An external heat source capable of heating a given material to its self-ignition temperature in a given environment.



2. A material with a self-ignition temperature below the temperature created by the heat source in the given configuration and environment.

*Example: A resistive element heater in a thermal runaway fault condition causing oxygen-wetted materials in the proximity to spontaneously ignite.*

### **Other Ignition Mechanisms**

1. Fresh metal exposure
2. Personnel smoking and open flames
3. Shock waves from tank rupture
4. Fragments from bursting vessels
5. Welding
6. Exhaust from thermal combustion engine
7. Lightning
8. Other heat generating mechanisms...





- II. Properties of the Oxidizer
  - a. Total pressure
  - b. Partial pressure of the oxidizer
  - c. Dynamics of contact between oxidizer and metal
  - d. Composition
  - e. Physical State
  - f. Thermal characteristics
  
- III. Properties of the Metal
  - a. Geometry
  - b. Surface conditions
  - c. Thermal characteristics
  - d. Mechanical characteristics
  - e. Composition
  - f. Mixing with oxidizer
  - g. Density
  - h. Oxide Formation
    - I. Protection
    - II. Adherence
    - III. Thermal Characteristics
    - IV. Composition
    - V. Density
    - VI. Stability