

Fire Resistance (LOI)



Flammability of Plastics

Combustion is a complex physio-chemical process between combustible material and oxygen, accompanied by heat release and light emission. “Flammability” is referred as capability of ignition, flame spreading and heat generation.

Flammability of Plastics is a result of the chemical nature of the carbon and hydrogen atoms in polymer chain, which are readily burned to produce carbon dioxide and water vapor.

Also, presence of other atoms like halogen atoms, aromatic compounds etc. or insufficient burning conditions (heat, oxygen...) can result in additional by-products upon burning of polymers.

Overall, aromatic polymers exhibit greater flame resistance than aliphatic polymers

Polymers’ inherent flammability can be divided into basis classes:

Inherently Flame Retardant	Less Flame Retardant	Quite Flammable
<ul style="list-style-type: none"> • Polytetrafluoroethylene • Aromatic polyethersulfone • Aromatic polyamides • Aromatic polyimides • Aromatic polyesters • Aromatic polyethers • Polyvinylidene dichloride 	<ul style="list-style-type: none"> • Silicones • Polycarbonates • Polysulfone • LCP (Liquid crystal polymers) <p style="text-align: center;"><i>These polymers can see high flame retardancy with the addition of additives</i></p>	<ul style="list-style-type: none"> • Polystyrene • Polyacetal • Acetals • Olefins (PP, PE...) • Polyurethane

The ability of polymer to burn depends on fire conditions as well as polymer formulations

The flammability is influenced by several factors such as:

- Ease of ignition – how rapidly a material ignites
- Flame spread – how rapidly fire spreads across a polymer surface
- Fire endurance – how rapidly fire penetrates a wall or barrier
- Rate of heat release – how much heat is released and how quickly
- Ease of extinction – how rapidly the flame chemistry leads to extinction
- Smoke evolution
- Toxic gas generation

Hence, the study of how plastics burn has been, and continues to be, a major area of research to examine the nature of the burning phenomenon in plastics, various methods to reduce plastics flammability, and methods to test flammability.

One of the widely used methods used to assess burning capability or flammability of polymer is: “**Limiting Oxygen Index or LOI**”.

View All Commercially Available Polymer Grades with Excellent Fire Resistance

Check out more on Fire Resistance (LOI):

- » **Limited Oxygen Index Values of Several Plastics**
- » **Limiting Oxygen Index Test and its Significance in Applications**
- » **How to calculate limiting oxygen index of polymers?**
- » **Composites and factors affecting LOI values**

What is Limiting Oxygen Index Test?

The purpose of the Limiting Oxygen Index (LOI) test, sometimes referred to as Oxygen Index (OI) or Critical Oxygen index (COI), is to measure the relative flammability of plastics and composite materials by burning them in a controlled atmosphere consisting of a mixture of oxygen and nitrogen.

The Limiting Oxygen Index represents the minimum level of oxygen in the atmosphere that can sustain flame on a thermoplastic material.

The higher the LOI value, the higher the non-flammability

The reasons for the differences between the polymers are various, but in particular two factors may be noted:

- The higher the hydrogen to carbon ratio in the polymer, the greater is the tendency to burning (other factors being equal).
- Some polymers on burning emit blanketing gases that suppress burning.

The test results relate only to the behavior of the test specimens under the conditions of this test method. The results must not be used to infer the fire hazards of the material in other forms or under other fire conditions.

Applications of LOI

LOI testing tool is used:

- As a quality control tool, during manufacturing of products and assemblies
- To indicate the potential flammability of a material
- And, as a semi-qualitative indicator of the effectiveness of additives during R&D

It is one of the primary characterizing tools used by plastic and electric cable industries as well as in military and transport manufacturing sectors.

How to Calculate Limiting Oxygen Index of Polymers?

The limiting oxygen index (LOI) is calculated using the formula:

$$\text{LOI} = \left[\frac{\text{O}_2}{(\text{O}_2 + \text{N}_2)} \right] * 100$$

Here, O₂ and N₂ are the minimum (oxygen and nitrogen respectively) concentrations in the inflow gases to pass the minimum burning length criterion.

The units of limiting oxygen concentration are: **Percentage, %**

Air contains approximately 21% oxygen and therefore any material with an LOI of less than 21% will probably support burning in an open-air situation.

The most generally used standard tests to calculate dielectric strength are:

- **ASTM D2863** - Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)
- **ISO 4589** - Determination of burning behavior by oxygen index:
 - Part 1: Guidance – It constitutes a guidance document for the OI test.
 - Part 2: Ambient-temperature test – It describes a method for determining the minimum concentration of oxygen by percentage volume in a mixture of oxygen and nitrogen introduced at $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ that will just support combustion of a material under specified test conditions.
 - Part 3: Elevated-temperature test – It describes methods of carrying out the same determination over a range of temperatures typically between 25°C and 150°C (although temperatures up to 400°C may be used). It is not applicable to materials having an OI value of less than 20, 9 at 23°C .

(ofcourse there exist several other flammability testing methods as well such as flash point determination, determination of burning rates, but they are not discussed here).

Limiting Oxygen Index – Test Apparatus



The LOI test apparatus consists of a heat-resistance glass column that allows the burning of the specimen to be observed. A slow stream of oxygen and nitrogen are pumped in at the base of the chimney where they pass through a layer of glass beads that ensures even mixing before entering the main test chamber. A small glass flame is used to ignite the upper end of the specimen, and the subsequent burning behavior is monitored.

The objective is to find the minimum oxygen concentration in nitrogen that will result in sustained combustion for at least 3 minutes or excessive flame propagation down the specimen.

- These methods are suitable for solid, laminated or cellular materials characterized by an apparent density 100 kg/m^3 or greater.
- The methods might also be applicable to some cellular materials having an apparent density of less than 100 kg/m^3 .
- A method is provided for testing flexible sheets or film materials while supported vertically.

Composites and Factors Affecting LOI Values

LOI values for highly flammable composites, such as polyester-, vinyl ester- and epoxy-based materials, are below about 30. **Composites** with highly stable or aromatic polymers have much **higher oxygen index values**.

In general, the LOI values for polymers and polymer composites increase with their ability to yield char in a fire. This is because the formation of char occurs at the expense of combustible volatiles, which in turn increases the oxygen level required to sustain flaming combustion.

In addition to the type of polymer matrix, **other factors that affect LOI value include:**

- The degree of resin cure
- Fiber content
- Flame retardants & other additives, and
- The flammability of the fiber reinforcement

The LOI values can also change dramatically with temperature, usually decrease with increasing temperature.

Check Out an Interesting Video on Combustibility Tests Equipment:

Oxygen Index Values of Several Plastics

Polymer Name	Min Value (%)	Max Value (%)
ABS - Acrylonitrile Butadiene Styrene	19.0	19.0
ABS Flame Retardant	28.0	28.0
ABS High Heat	18.0	19.0
ABS High Impact	18.0	19.0
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	21.0	34.0
ABS/PC Blend 20% Glass Fiber	24.0	24.0

Amorphous TPI, Highest Heat, Chemical Resistant, 260C UL RTI	53.0	53.0
Amorphous TPI, Moderate Heat, Transparent	45.0	45.0
Amorphous TPI, Moderate Heat, Transparent (Food Contact Approved)	45.0	45.0
Amorphous TPI, Moderate Heat, Transparent (Mold Release grade)	45.0	45.0
Amorphous TPI, Moderate Heat, Transparent (Powder form)	45.0	45.0
ASA - Acrylonitrile Styrene Acrylate	19.0	19.0
ASA/PC Blend - Acrylonitrile Styrene Acrylate/Polycarbonate Blend	21.0	21.0
CPVC - Chlorinated Polyvinyl Chloride	70.0	80.0
ETFE - Ethylene Tetrafluoroethylene	30.0	30.0
EVA - Ethylene Vinyl Acetate	18.0	19.0
FEP - Fluorinated Ethylene Propylene	95.0	96.0
HDPE - High Density Polyethylene	17.0	18.0
HIPS - High Impact Polystyrene	17.0	18.0
HIPS Flame Retardant V0	17.0	26.0
LCP - Liquid Crystal Polymer	35.0	50.0
LCP Carbon Fiber-reinforced	33.0	37.0
LCP Glass Fiber-reinforced	37.0	51.0
LCP Mineral-filled	33.0	37.0
LDPE - Low Density Polyethylene	17.0	18.0
LLDPE - Linear Low Density Polyethylene	17.0	18.0
PA 11 - (Polyamide 11) 30% Glass fiber reinforced	22.0	22.0

PA 11, Conductive	21.0	26.0
PA 11, Flexible	21.0	26.0
PA 11, Rigid	21.0	26.0
PA 12 (Polyamide 12), Conductive	21.0	26.0
PA 12, Fiber-reinforced	21.0	26.0
PA 12, Flexible	21.0	26.0
PA 12, Rigid	21.0	26.0
PA 46 - Polyamide 46	24.0	24.0
PA 46, 30% Glass Fiber	21.0	23.0
PA 6 - Polyamide 6	23.0	26.0
PA 6-10 - Polyamide 6-10	23.0	27.0
PA 66 - Polyamide 6-6	21.0	27.0
PA 66, 30% Glass Fiber	21.0	27.0
PA 66, Impact Modified	21.0	27.0
Polyamide semi-aromatic	21.0	27.0
PAI - Polyamide-Imide	44.0	45.0
PAR - Polyarylate	26.0	30.0
PARA (Polyarylamide), 30-60% glass fiber	25.0	25.0
PBT - Polybutylene Terephthalate	20.0	24.0
PBT, 30% Glass Fiber	21.0	21.0
PC (Polycarbonate) 20-40% Glass Fiber	30.0	34.0
PC (Polycarbonate) 20-40% Glass Fiber Flame Retardant	35.0	40.0
PC - Polycarbonate, high heat	24.0	35.0
PCTFE - Polymonochlorotrifluoroethylene	90.0	95.0

PE - Polyethylene 30% Glass Fiber	17.0	19.0
PEEK - Polyetheretherketone	24.0	35.0
PEEK 30% Glass Fiber-reinforced	35.0	40.0
PEI - Polyetherimide	46.0	47.0
PEI, 30% Glass Fiber-reinforced	50.0	50.0
PEI, Mineral Filled	48.0	48.0
PEKK (Polyetherketoneketone), Low Crystallinity Grade	40.0	40.0
PESU - Polyethersulfone	34.0	38.0
PESU 10-30% glass fiber	45.0	45.0
PET - Polyethylene Terephthalate	23.0	25.0
PET, 30% Glass Fiber-reinforced	21.0	23.0
PET, 30/35% Glass Fiber-reinforced, Impact Modified	21.0	21.0
PETG - Polyethylene Terephthalate Glycol	23.0	25.0
PE-UHMW - Polyethylene Ultra-High-Molecular-Weight	17.0	18.0
PFA - Perfluoroalkoxy	95.0	96.0
PI - Polyimide	47.0	53.0
PLA - Polylactide	1.230	1.250
PMMA - Polymethylmethacrylate/Acrylic	19.0	20.0
PMMA (Acrylic) High Heat	19.0	20.0
PMMA (Acrylic) Impact Modified	19.0	20.0
PMP - Polymethylpentene	17.0	53.0
PMP 30% Glass Fiber-reinforced	17.0	18.0
PMP Mineral Filled	17.0	18.0
POM - Polyoxymethylene (Acetal)	18.0	18.0

POM (Acetal) Impact Modified	18.0	18.0
PP - Polypropylene 10-20% Glass Fiber	17.0	18.0
PP, 10-40% Mineral Filled	17.0	18.0
PP, 10-40% Talc Filled	17.0	18.0
PP, 30-40% Glass Fiber-reinforced	17.0	18.0
PP (Polypropylene) Copolymer	17.0	18.0
PP (Polypropylene) Homopolymer	17.0	18.0
PP, Impact Modified	17.0	18.0
PPE - Polyphenylene Ether	22.0	24.0
PPE, 30% Glass Fiber-reinforced	24.0	26.0
PPE, Flame Retardant	30.0	36.0
PPS - Polyphenylene Sulfide	43.0	47.0
PPS, 20-30% Glass Fiber-reinforced	43.0	49.0
PPS, 40% Glass Fiber-reinforced	43.0	49.0
PPS, Glass fiber & Mineral-filled	45.0	53.0
PPSU - Polyphenylene Sulfone	44.0	44.0
PS (Polystyrene) Crystal	17.0	18.0
PS, High Heat	17.0	18.0
PSU - Polysulfone	30.0	32.0
PSU, 30% Glass fiber-reinforced	36.0	36.0
PTFE - Polytetrafluoroethylene	95.0	96.0
PTFE, 25% Glass Fiber-reinforced	95.0	96.0
PVC (Polyvinyl Chloride), 20% Glass Fiber-reinforced	40.0	45.0
PVC, Plasticized	20.0	40.0
PVC, Plasticized Filled	20.0	40.0

PVC Rigid	40.0	45.0
PVDF - Polyvinylidene Fluoride	44.0	83.0
SAN - Styrene Acrylonitrile	18.0	19.5
SAN, 20% Glass Fiber-reinforced	20.0	20.0
SRP - Self-reinforced Polyphenylene	49.0	55.0
TPI-PEEK Blend, Ultra-high heat, Chemical Resistant, High Flow, 240C UL RTI	42.0	42.0
XLPE - Crosslinked Polyethylene	17.0	18.0