www.ijarp.com ISSN 2456-9992 Page: 01-11
International Journal Advanced Research Publications
Review Article
Volume: 02
Issue: 05

POLYMER FIRE SUPPRESSION SYSTEM

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Article Received: 05 April 2026, Article Revised: 25 April 2026, Published on: 15 May 2026

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DOI: https://doi-doi.org/101555/ijarp.8825

ABSTRACT:

Polymers are used extensively in manufacturing and household products, but because they may burn in solid, liquid, and gas phases, they present a serious fire risk. Polymer fires can be made worse by conventional firefighting techniques, which release poisonous and combustible fumes. Because it displaces oxygen and lowers flame temperature, a water mist fire suppression system is the most effective; nevertheless, its effectiveness depends on droplet size and pressure. The tuning of nozzle parameters for efficient fire extinguishment is informed by testing polymer behaviour using burning rate tests and decomposition temperature using Differential Scanning Calorimetry (DSC). According to experimental results, effective extinguishment depends on nozzle placement and design in addition to pressure, which eventually shortens extinguishment times and uses less water.

KEYWORDS: Polymer Science, Water Mist Fire Suppression, Droplet Size, Burning Rate Test, Differential Scanning Calorimetry, Decomposition Temperature, Nozzle Design, Fire Extinguishment Efficiency.

INTRODUCTION

Although fire is essential to human growth, it also poses serious threats to life and property, particularly in India, where fire accidents claimed 23,281 lives in 2012. Fire department actions, laws, and fire safety education initiatives are examples of societal responses. Combustion, which needs fuel, an oxidizer, and heat to maintain a fire, is explained by the fire tetrahedron model. Under certain circumstances, a variety of fuels, including flammable liquids and discarded waste items, can catch fire. In contrast to the reckless disposal of materials like plastic, which poses special issues in fire management, proper storage and safety measures are essential to reduce fire threats, especially in industrial settings where fuels like gasoline and diesel are handled with safeguards.

POLYMER

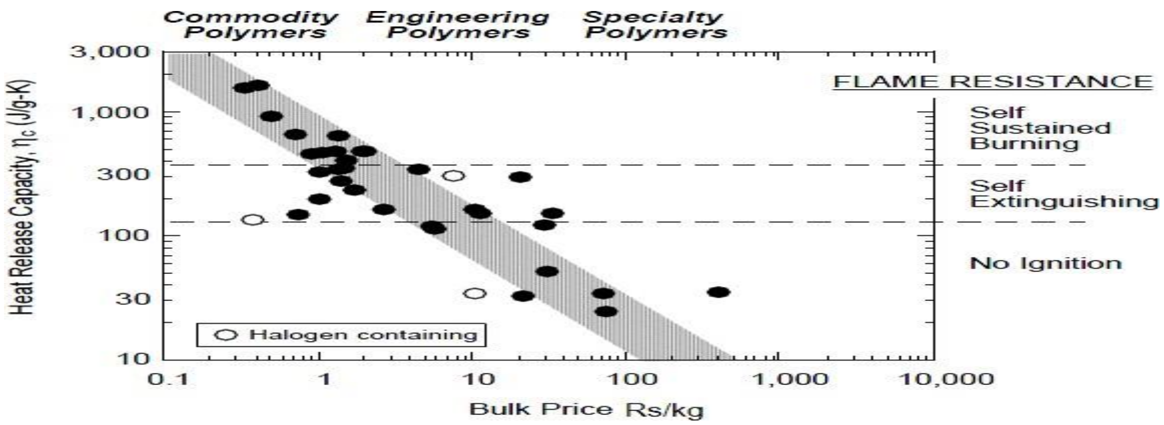
A crucial class of high molecular mass materials, polymers are present in commonplace products including rubber, plastic, adhesives, and resins. The Greek words "poly" (many) and "mers" (parts or units) are where the word "polymer" originates. Polymers, sometimes referred to as macromolecules, are made up of numerous smaller components called monomers that are joined together by a process called polymerization. In this chemical reaction, two or more compounds combine to form a high molecular weight molecule, or polymer, from monomers, which are the initial elements. Table 1.1 summarizes the many ways in which polymers can be classified according to their wide variety of chemical structures, physical attributes, mechanical behaviours, and thermal characteristics.

Table 1 Classifications of Different Types of Polymers.

Sl no	Basis of Classification	Polymer Type
1	Origin	Natural, Semi synthetic, Synthetic
2	Thermal Response	Thermoplastic, Thermosetting
3	Mode of formation	Addition, Condensation
4	Line structure	Linear, Branched, Cross-linked
5	Application and Physical Properties	Rubber, Plastic, Fibers
6	Tacticity	Isotactic, Syndiotactic, Atactic
7	Crystallinity	Non crystalline(amorphous), Semi-crystalline, Crystalline
8	Polarity	Polar, non-polar
9	Chain	Hetro, Homo-chain

POLYMER FIRE

Plastics, or polymers, constitute an increasing portion of the fire load in residential, industrial, and transportation sectors. The most commonly used plastics are often the least expensive and highly flammable. Flammability, defined as the tendency of a substance to ignite and melt quickly, indicates fire risk. A referenced figure illustrates the relationship between flammability metrics—specifically heating discharge capacity and flame resistance—relative to the cost of commercial polymers. Notably, commodity polymers priced below approximately 37 rupees per kilogram account for over 95% of usage and continue to burn even with minimal flame exposure. In contrast, engineering and specialty plastics, which cost more than 74 rupees per kilogram, generally include aromatic backbones and fluoropolymers that exhibit self-extinguishing properties due to superior thermal stability or lower energy values. The figure further reveals that while flame resistance does not consistently correlate with price, it shows a moderate correlation with heat release capacity.



THE BURNING PROCESS

Gases and volatile fluids consist of small particles connected by weak secondary chemical bonds, leading to the creation of easily ignitable combustible mixtures with air. Polymers, being large macromolecules, possess similar intermolecular and intramolecular forces but have an effectively infinite boiling temperature due to their high molecular weight. The conversion of polymers into volatile energy species requires breaking both types of bonds, necessitating a continuous and substantial source of heat for ignition and sustained combustion.

Flaming combustion can be categorized into chemical and physical processes across three distinct phases: condensed, mesophase, and gas. The mesophase serves as the interface between the gaseous and condensed stages during combustion. Energy transport via convection and radiation occurs between the mesophase and the flame, while energy loss happens through mass transfer and conduction. At typical combustion rates, the polymer surface in the mesophase recedes at speeds around 10^6 m/s, while the evolution of gases occurs at roughly 10^3 m/s, significantly slower than the burning velocity of these gases when mixed with air (1 m/s). Hence, the growth of fuel is the rate-limiting step in polymer flaming combustion, primarily governed by the transfer rates of mass and temperature to and from the polymer.

The core chemical processes include thermal degradation of the polymer in the mesophase, mixing of volatile pyrolysis products with air through diffusion, and combustion of this fuel-air mixture, resulting in emitted light across a spectrum of wavelengths. The combustion zone is characterized by a fuel-rich region internally and a fuel-lean region externally. Enhancing the oxygen concentration in the environment is recognized to elevate the flame heat flux due to higher flame temperatures, increased combustion zone volume, or greater soot concentration (luminosity). The specific physical and chemical activities relevant to each phase of flaming combustion are depicted in accompanying.

PROBLEM IDENTIFICATION

The polymers are substance that is most often used in market and households in large amount, this content doesn’t catch fire easily. But when it catches fire, it's tough to extinguish the fire and additionally, it creates dangerous gases. The significant problem related to polymer fire suppression is

- Polymer fire creates lack of presence by smoke & emits dangerous gases therefore physical firefighting of the polymer fire can't be done, so immediate fire suppression should be offered to extinguish the flame.
- Larger polymeric fires may end up from chemical enhancement of the burning rate if fire suppressants are discharged from a badly designed system.
- Non flaming combustion, which includes glowing combustion and shouldering, propagates via the polymer by way of a thermal trend or front, concerning the area oxidation of the pyrolysis products, therefore speed of extinguishment is slow.
- Most of the polymers utilized in the house hold and in the market are of lower quality and that doesn't possess the home of self-extinguishing or perhaps prohibiting the fire spread.
- When the polymer compounds are burnt it also creates combustible fumes that will more get involved in the combustion and much more heat radiation will be produced.
- Polymer fire is going to make the polymers in a semi stable form, therefore when forced water or maybe a lot pressurized water is created to impinge on polymer the flame will spread quite quickly, so for this job the fine spray of extinguishing agent must be utilized.

METHODOLOGY

The flowchart for the project in phase I and phase II is shown in the figure 1 and figure 2 respectively.

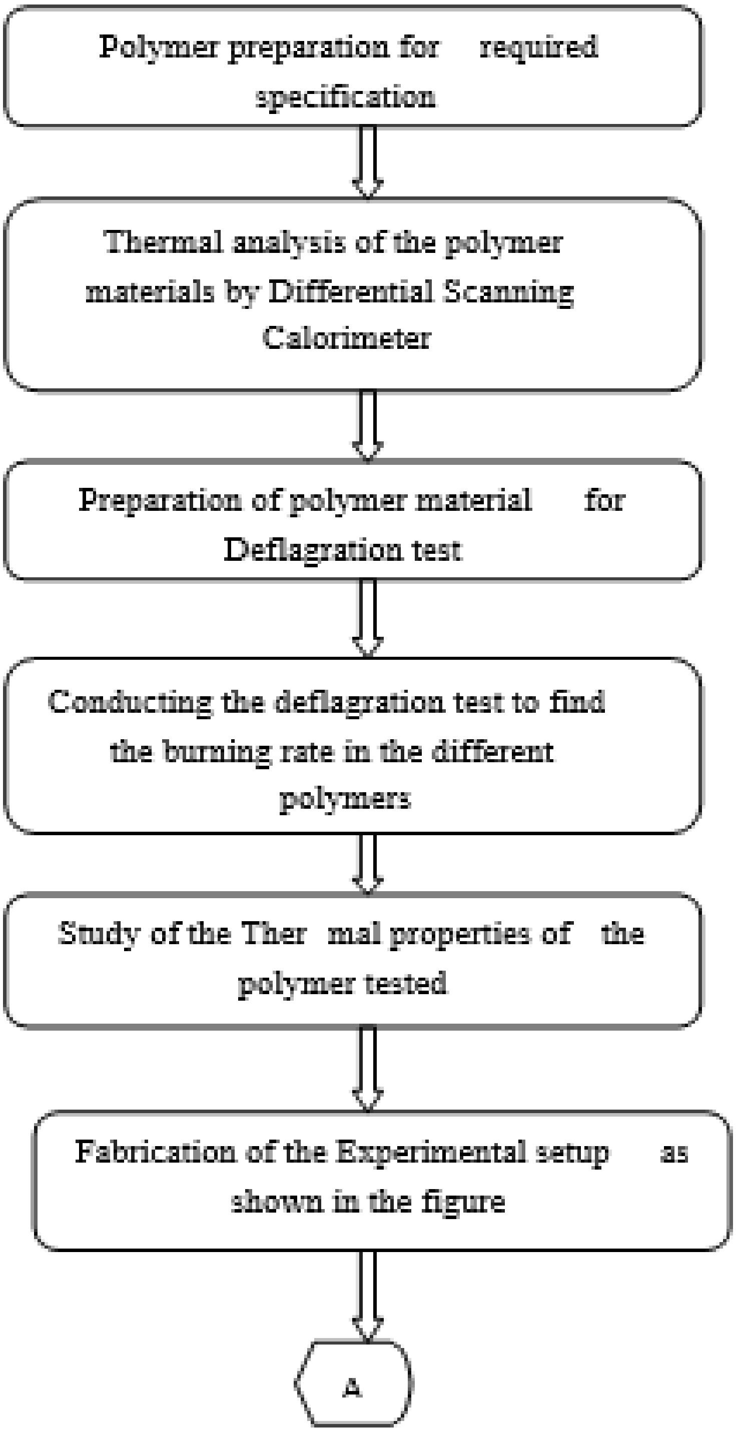


Figure 1 Methodology Flowcharts for Phase I.

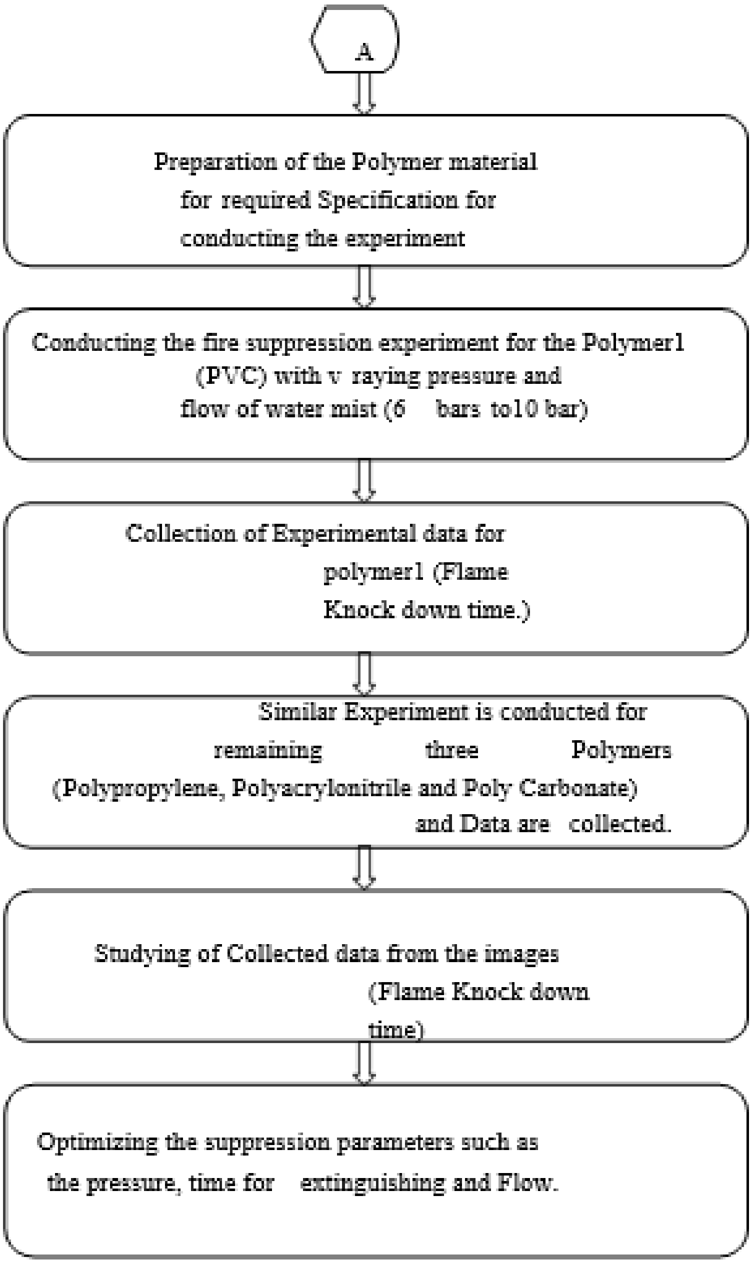


Figure 2 Methodology Flowchart for Phase 2.

BURNING RATE TEST

In a laboratory context, the 05 Standard Test Method for Rate of Burning of Plastics assesses the flammability of polymeric materials by measuring their linear rate of burning or the degree and duration of burning when placed horizontally. This technique is intended for polymers used in equipment and appliances that are shaped like bars or panels. Although it offers a preliminary indication of flammability acceptability, it does not address every factor necessary for thorough fire danger evaluations under actual circumstances. Additional assessments that follow pertinent guidelines for the entire apparatus in which these materials are utilized are necessary for final material approval.

Test Fixture

A laboratory ring stand or maybe test fixture built with a little clamp permitting the specimen to be kept because of its longitudinal axis horizontal and its transverse axis inclined at 45+or2° angle as illustrated. The fixture will be able to with stand the heat created from polymer fire. The diagram on the test fixture is found in figure 3.

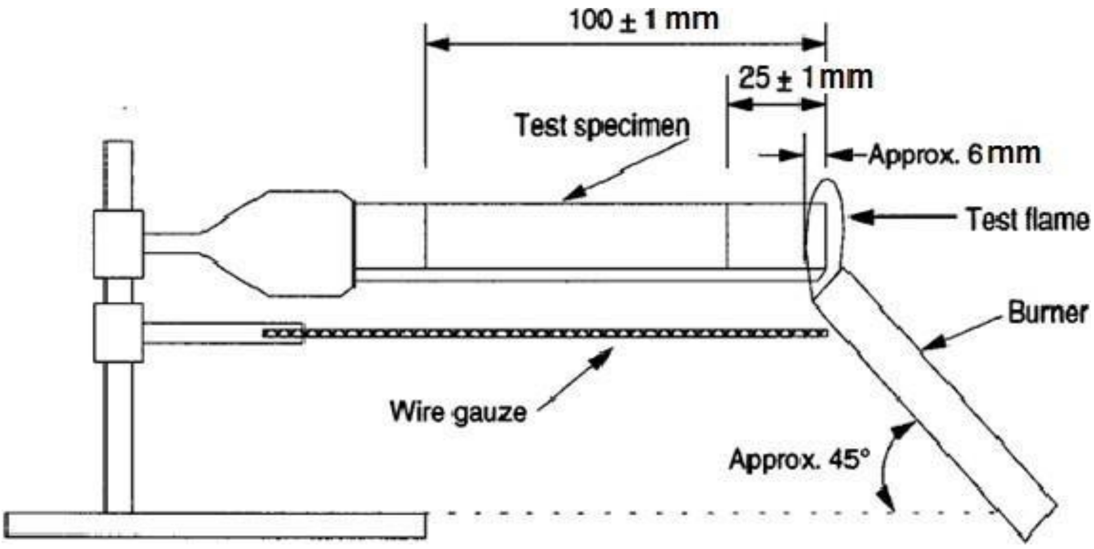


Figure 3 Test Fixture.

TEST SPECIMEN

Test specimens must be formed into the required shape or obtained from a representative material sample. For a smooth finish, surfaces should be cleaned after cutting and the edges should be lightly sanded. The dimensions of the specimens should be 125 ± 5 mm in length, 13.0 ± 0.5 mm in breadth, and at least 3.0 mm in thickness, with a maximum of 13 mm in thickness and 13.5 mm in width. It is necessary to have smooth edges and corners with a radius of no more than 1.3 mm. An example is a polymer sample that is 10 mm thick, cut to 150 mm length and 13 mm width, and has its edges filed and smoothed according to specifications. Figures showing several polymer samples, including polyacrylonitrile, polycarbonate, polyvinyl chloride, and polypropylene, according to specified dimensions are cited in the text.

Table .1 Polymer sample specimen.

S. No	Sample Name	Length (mm)	Width(mm)	Thickness(mm)	Quantity in numbers
1	Polypropylene	150	13	10	5
2	Polypropylene	150	13	8	5
3	Polypropylene	150	13	6	5
4	Polycarbonate	150	13	10	5
5	Polycarbonate	150	13	8	5
6	Polycarbonate	150	13	6	5
7	Polyacrilonitrile	150	13	10	5
8	Polyacrilonitrile	150	13	8	5
9	Polyacrilonitrile	150	13	6	5
10	Polyvinylchloride	150	13	10	5
11	Polyvinylchloride	150	13	8	5
12	Polyvinylchloride	150	13	6	5

FABRICATION OF WATER MISTSYSTEM

A water mist system consists of a high-pressure fire-retardant gas cylinder that uses argon, carbon dioxide, or nitrogen to force water through a nozzle. Even when the water runs out, these gasses put out fires. A water reservoir, pressure gauge, valve, and nozzle with an orifice diameter of less than 1 mm—usually composed of rust-resistant stainless steel—are all part of the system. Tubing ensures system integrity by withstanding high pressure. Modern systems contain fire sensing devices that, when a fire is detected, trigger a solenoid valve to release mist. These units are appropriate for a variety of fire types, including kitchen and chemical fires. With little physical harm, this technique makes post-suppression clean-up simple. This description may be accompanied by a schematic diagram.

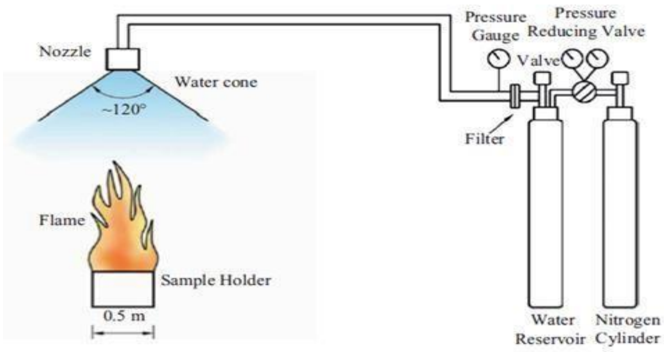


Figure 4 Schematic diagram of water mist system.

WORKING OF WATER MISTSYSTEM

The nitrogen cylinder will be having two valve one for opening the nitrogen cylinder and other for controlling the outlet pressure. The pressure in the regulator is set to required bar and the nitrogen will flow into the water reservoir. Pressure in the system is noted in the pressure gauge after the required pressure is attained the ball valve will be opened which allow the water to pass to the nozzle.

Figure 5 Experimental set up.

CONCLUSION

Polymer Science based fire studies confirm that polymer materials present a major fire hazard because they can burn in solid, liquid, and gaseous phases while emitting dense smoke, toxic fumes, and combustible gases. Traditional firefighting techniques are often less effective and may even intensify fire conditions by spreading molten polymers and increasing hazardous emissions. Therefore, advanced suppression technologies are essential for improving fire safety in industries and residential environments.

Among available suppression methods, Water Mist Fire Suppression systems have proven to be one of the most efficient and environmentally friendly solutions. Water mist works by absorbing heat rapidly, reducing oxygen concentration near the flame, and cooling combustible surfaces. The effectiveness of the system is strongly influenced by Droplet Size, spray velocity, and operating pressure, as smaller droplets provide better heat absorption and faster evaporation.

Experimental investigations using Burning Rate Test techniques help evaluate flame spread and combustion intensity, while Differential Scanning Calorimetry determines the Decomposition Temperature and thermal stability of polymers. These analyses provide essential data for designing efficient fire suppression systems and selecting suitable operational conditions.

The study also highlights that proper Nozzle Design and nozzle placement are as important as pressure optimization. Efficient nozzle configurations improve mist distribution, increase flame coverage, and reduce extinguishment time while minimizing water usage and secondary damage. Overall, optimized polymer fire suppression systems enhance fire safety, improve extinguishing performance, reduce environmental impact, and provide a reliable solution for protecting industrial facilities, storage areas, and household applications from polymer-related fire hazards.

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