Handbook for Design of Structures under Fire and Blast Loads

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By

Srinivasan Chandrasekaran
and Pradeepa M.

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PREFACE

This book covers the necessary domain of understanding structural fire design. While the focus is mainly with respect to steel structures, the main strength of the book lies in the presentation of coupled thermal-structural analysis, which is relatively new. The book explains the design concepts in a simple and illustrative manner, making it very convenient for self-learning. The presented material is useful for both academic and research purposes, while consulting engineers will enjoy the design examples and explanations. Step-by-step illustrations of fire-resistant analysis, described at the end of the book, shall be useful to strengthen the capacity building in this domain of engineering. Front End Engineering Design (FEED) concepts discussed in the second chapter is an attempt to integrate fire-resistant design in the planning stage itself. The risk assessment methods and use of flammability diagrams discussed in the book are essential for consulting and practicing engineers. Authors are well-experienced academicians and practicing consultants, whose teaching skills and consulting methods paved classroom teaching material for the readers.

Although many modern structural systems are designed to develop their capacity from a geometric form, material strength is inherent to achieving the desired capacity. In this book, a detailed coupled analysis of thermal and structural sections is discussed with a step-by-step approach to the software intended for such designs. Material properties at elevated temperatures and various parameters that influence the strength at high temperatures are presented to enhance the understanding of the material behavior at high temperatures.

It is to be noted that the probability of the occurrence of fire in a building is significantly greater than that of the building experiencing a major earthquake during its design life. Hence, appropriate treatment of fire scenarios in the design of structures should be mandatory. Fire development process within the compartment and various empirical fire development models that consider fire load and ventilation conditions are also discussed in detail. Additionally, the book also discusses temperature progression at different stages of fire in terms of standard and parametric fire time-temperature curves. Design under blast loads is not well-addressed in the literature but is in high demand amongst practicing engineers. A dedicated chapter in this book helps understand the blast forces and the methods of analysis.

The authors express their immense gratitude to all research scholars, graduate students, and colleagues for their support in various capacities. The lead author thanks the Chairman, Centre of Continuing Education, Indian Institute of Technology Madras, for extending the administrative support in preparing the manuscript of this book. The authors thank all the lead academicians who were kind enough to present the foreword for this book. Authors also thank Thunderhead Engineering (Pyrosim software) and Mathworks Inc, USA (Matlab) for their kind permission to use the graphical illustrations of the results obtained from the software.

Srinivasan Chandrasekaran
Pradeepa, M

FOREWORD

The increasing complexity of industrial structures, offshore platforms, and petrochemical facilities necessitates a robust and comprehensive approach to mitigating the risks posed by fire and blast hazards. The Handbook for Design of Structures under Fire and Blast Loads is a timely and essential resource that bridges the gap between theoretical principles and practical applications in structural fire and blast engineering.

Authored by renowned experts in structural and offshore engineering, this book reflects decades of research and industry experience, offering insights that will undoubtedly contribute to advancements in fire-resistant and blast-resistant structural design. It provides a strong foundation for developing innovative design strategies that enhance structural safety and performance under extreme conditions.

What makes this handbook particularly valuable is its integration of real-world case studies, advanced computational modeling, and best practices in fire and blast mitigation. It serves as a critical reference for engineers and researchers seeking to enhance the resilience of infrastructure against extreme events. By combining scientific rigor with practical insights, this book empowers professionals to develop safer, more robust structural designs in high-risk environments.

Professor Rouzbeh Abbassi, P. Eng.
Director of Research, School of Engineering,
Macquarie University, Australia

FOREWORD

I am glad to write the foreword for the book titled **Handbook for Design of Structures under Fire and Blast Loads**, authored by Srinivasan Chandrasekaran and Pradeepa. The book covers important aspects of structural design under fire, explosion, and blast loads, which is scarcely dealt with in detail in the literature. With the increasing accidents in industrial units under fire and explosion, the study material of this book is very useful for practicing engineers to strengthen their capacity building in this domain of engineering. Covering fire chemistry, explosion characteristics, thermal-structural analysis, and fire protection strategies, this book bridges the gap between theory and real-world application. It introduces methodologies such as FEED frameworks, fire scenario modeling, and sequential thermal-structural analysis to help professionals assess risks and enhance structural safety.

The tailor-made contents for structural engineers, fire safety consultants, and offshore industry professionals, this book is a useful Handbook of reference in the design offices offering essential knowledge and tools to mitigate fire and blast hazards. With case studies, best practices, and design insights, it serves as a crucial reference for those aiming to protect lives and assets in high-risk environments. The authors are well-known in the domain of structural engineering, while Srinivasan Chandrasekaran is one of the well-decorated international experts in the academic, research, and consulting fields, testified by authoring a large number of textbooks and research publications.

I strongly recommend a copy of this book in your library as this will serve as a useful reference, for sure.

Professor Arvind Kumar Jain
Former Head,
Dept. of Civil Engineering
Indian Institute of Technology Delhi
India

FOREWORD

Over the last few years, a deep understanding of blast and fire effects in designing critical buildings and infrastructure has developed significantly. The importance of this knowledge was realized when significant disasters, such as Alpha Piper, occurred in the last three decades. Structures posing high risks of blast and fire hazards must protect lives, the environment, and valuable assets. The philosophy of designing structures to withstand blast and fire loads is based on a multifaceted approach, which involves selecting highly resilient materials, ensuring high ductility and redundancy of the structural system, and offering strategies for mitigating the disastrous effects. In the event of a fire, the structural materials rapidly lose their stiffness, and due to the explosion, they undergo significant plastic deformation. Therefore, nonlinear dynamic analysis methods are employed in the design processes.

This book is written to provide a detailed understanding of the perceived performance of structures under blast and fire hazards. It helps revisit design principles and the fundamental fire and blast mechanisms theories. Emphasis is given to offshore structures requiring higher safety and reliability. The book contains six chapters: Chapter one discusses fire chemistry, such as the basis of fire and its characteristics; fire modeling, including hydrocarbon fire, consequences, and vulnerability factors. The second chapter discusses the front-end engineering design (FEED) framework for an offshore topside structure subjected to fire and explosion effects. Chapter three presents the preliminary and detailed design concept of sequential thermal and structural analysis, such as load combinations, fire scenarios and simulation, heat transfer, stress-deformation analysis, and a fire rating system. Chapter four provides an understanding of active and passive fireproofing concepts and systems. Chapter five is dedicated to blast-resistant design, including the theory of blast wave propagation, structural performance under blast, methods of analysis, and design. The final chapter, Chapter Six, contains a framework of structural fire engineering. In short, these six chapters confined a deep and comprehensive knowledge of fire and blast-resistant structural design. Since this kind of design involves rigorous analysis using computational tools, appendices include MATLAB coding for the design of fire and blast-resistant structures. Therefore, this handbook will be an essential reference to the library of structural engineering professionals, fire safety consultants, and offshore engineering professionals. Srinivasan Chandrasekaran, the principal author of this book, is a well-known academician with international accolades. Many other books authored by him are quite popular and referred to in many universities all over the world. I am very confident that I can recommend this book to practicing engineers and graduate students who are learning fire resistance design in a classroom model.

Nasir Shafiq
Ph.D. in Structural Engineering and Materials (Leeds, UK)
Professor Civil (Structural) Engineering
Universiti Teknologi PETRONAS
Malaysia

FOREWORD

It is with great pleasure that we present the *Handbook for Design of Structures under Fire and Blast Loads*, a significant contribution to structural engineering. This book serves as a vital resource for engineers, researchers, and practitioners seeking to enhance their understanding of the complex challenges associated with designing structures to withstand fire and blast effects. Structural resilience against extreme loading conditions is of paramount importance in modern engineering, particularly in industries where safety and reliability are critical. This handbook provides a well-structured compilation of fundamental principles, advanced methodologies, and practical case studies that bridge the gap between theoretical knowledge and real-world applications. The book offers valuable insights into developing safer and more robust structures by integrating international standards and best practices.

As supporters of this work, we recognize the importance of research and knowledge dissemination in advancing engineering practices. We are honoured to contribute to this initiative, which we believe will benefit the academic and professional community and help shape safer infrastructure for the future. We extend our sincere appreciation to the authors, Dr. Srinivasan Chandrasekaran and Dr. Pradeepa, for their dedication and expertise in bringing this valuable resource to life. We hope that this book will serve as a lasting reference for those committed to excellence in structural design and safety.

Dr. Sarinya Sanitwong Na Ayutthaya
Dean, Faculty of International Maritime Studies
Kasetsart University,
Sri Racha campus, Chonburi,
Thailand

CHAPTER 1

FIRE CHEMISTRY

1.1 Introduction

This chapter covers the combustion process, explaining the fire triangle and fire tetrahedron. It classifies fires based on the types of fuels involved, including solids, flammable liquids, gases, and electrical sources. The characteristics and consequences of fire and explosions, including combustion rates, flame spread, and thermal radiation, are examined alongside key vulnerability factors. The chapter also discusses fire scenario development and the hazards of hydrocarbon fires, which are known for their extreme heat. Finally, it introduces fire modelling techniques, essential for predicting fire growth and structural response, forming the basis for advanced studies on fire safety and protection.

1.2 Chemical Process of Fire Combustion

Fire is a complex chemical process that involves rapid oxidation, releasing heat, light, and combustion gases. This reaction, known as combustion, requires three fundamental components: fuel, Oxygen, and heat. These elements form the **fire triangle**, a simple model that explains the necessary conditions for fire to ignite and sustain itself. If any of these components are removed, such as cutting off the oxygen supply, cooling the material below its ignition temperature, or eliminating the fuel, the fire will be extinguished.

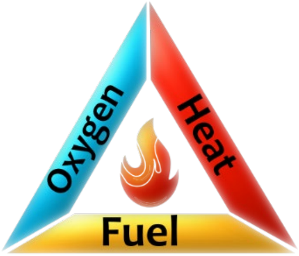

Fig. 1.1 Fire triangle

However, the fire triangle does not fully explain why fire can sustain itself once ignited. Fire science introduces the **fire tetrahedron** to address this, which adds a fourth crucial component: **chemical chain reactions**. Once a fire starts, the breaking down of fuel molecules releases free radicals, highly reactive atoms or molecules that continue to react with Oxygen. These chain reactions generate additional heat, further breaking down more fuel and creating a self-sustaining process.

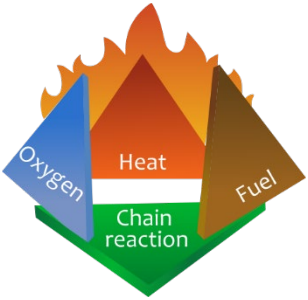

Fig. 1.2 Fire tetrahedron

A common example illustrating both models is a candle flame. The wax acts as the fuel, air provides Oxygen, and the initial ignition source (such as a match) supplies the heat. Once the wax melts and vaporises, it reacts with Oxygen to maintain the flame. The fire tetrahedron comes into play when the heat generated by the combustion process keeps vaporising more wax, allowing the flame to continue burning even after the match is removed. If any element, fuel (wax), Oxygen (air), heat (from the flame), or the chain reaction (sustained combustion) is disrupted, the candle will extinguish.

Fundamentals of Combustion

Fire progresses through distinct stages: ignition, growth, full development, and decay. Understanding these stages is critical for effective fire prevention and emergency response.

The first stage is **ignition**, which occurs when a fuel source encounters sufficient heat. This initial heat raises the temperature of the fuel to its ignition point, resulting in the onset of combustion. For instance, striking a match against its box produces frictional heat that ignites the matchstick. At this initial stage, extinguishers or immediate suppression methods, like using a fire blanket or foam extinguisher, are effective.

Following ignition, the fire enters the **growth** phase. During this phase, the fire spreads rapidly through several heat transfer mechanisms: conduction, convection, and radiation (Karlsson and Quintiere 2022). For example, consider a room with a burning sofa. The flame initially heats the surrounding air through convection, and the air rises, spreading heat upwards. Simultaneously, heat conducts into nearby wooden furniture, potentially igniting it. Radiation also spreads heat directly to other combustible materials in the room, escalating the fire's intensity. In this phase, rapid intervention using hose reels, water sprinklers, or fire suppression systems can control the fire spread and prevent it from escalating.

If sufficient fuel and Oxygen are available, the fire eventually transitions into the fully developed **burning** phase. Here, the fire achieves its maximum intensity, characterised by high temperatures and extensive flame spread. In this phase, flames engulf much of the available combustible material, creating hazardous conditions and significantly endangering structural integrity. An example is a room engulfed by flames. During this stage, firefighting shifts to defensive strategies aimed at containment. Firefighters often deploy heavy-duty hoses and firefighting foam, focusing primarily on preventing the fire from spreading to adjacent spaces rather than directly suppressing it inside the engulfed area.

Finally, the fire enters the **decay** phase. This stage begins as the fuel supply diminishes or available oxygen levels decrease. Consequently, fire intensity and heat output decrease substantially. An example scenario is the fire in a fireplace reducing in size and intensity as the wood burns completely, eventually extinguishing entirely. At this stage, firefighters can safely approach to extinguish remaining hotspots using targeted water sprays, thermal imaging to identify hidden embers, and conducting ventilation to disperse residual heat and gases.

Fig. 1.3 illustrates two distinct fire curves: the standard fire curve and the natural fire curve. The standard fire curve, depicted as steadily increasing without decline, represents controlled conditions typically used in the laboratory testing of materials and structural components. It provides a consistent reference to measure fire resistance. In contrast, the natural fire curve closely mirrors real-world fires, clearly showing phases of ignition, growth, fully developed burning, and decay. Notably, it features a pronounced peak temperature during the fully developed stage, followed by a rapid decline as fuel and oxygen decrease, accurately reflecting the dynamic and variable nature of real fire scenarios.

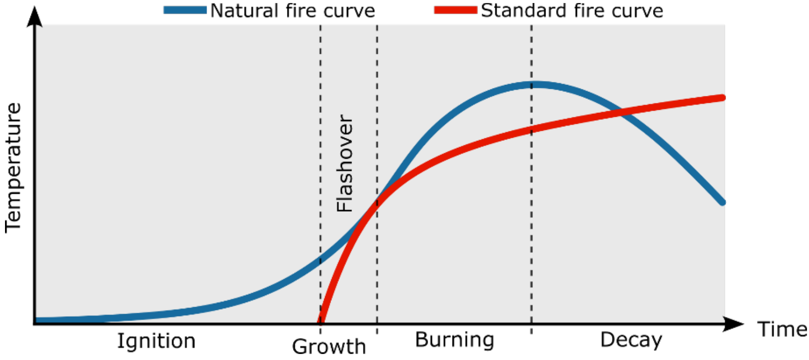

Fig. 1.3 Different stages of fire development

The standard fire curve has significant importance, especially in structural design and fire resistance testing. It serves as a consistent, repeatable, and universally accepted benchmark. Using this curve, engineers can reliably compare the fire resistance of different materials and structural systems under uniform conditions. This consistency allows standardised fire ratings, helping designers and regulators ensure safety compliance across different regions and building types.

A natural fire curve, although realistic, varies considerably based on fuel types, ventilation, and compartment size. These variations make natural fire curves unpredictable and challenging to reproduce precisely for standard testing or comparisons. For practical design purposes, repeatedly creating a precise natural fire scenario at every stage would be complex and computationally expensive.

Therefore, the standard fire curve offers a simplified yet effective way to assess structural safety consistently. Natural fire curves can complement these assessments by providing insights into realistic scenarios but are less practical for routine testing and regulatory compliance.

Fire Dynamics and Heat Transfer

The behaviour of fire is strongly influenced by heat transfer mechanisms: conduction, convection, and radiation. Understanding these mechanisms is essential for predicting fire growth and structural response under fire conditions.

Conduction transfers heat through solid materials. It occurs when vibrating atoms and molecules transfer energy directly to neighbouring particles. The governing equation for conduction, known as Fourier's law, is given by:

$$q = -k\frac{dT}{dx} \tag{1.1}$$

where q is the heat flux (W/m^2), k is the thermal conductivity of the material (W/m K), and $\frac{dT}{dx}$ is the temperature gradient. For example, heat conducting through a steel beam in a building fire can significantly reduce its strength and stability.

Convection involves the movement of heat by fluid (air or gases) currents. It is the primary driver of fire spread in enclosed spaces. The governing equation for convective heat transfer is Newton's law of cooling:

$$q = h(T_s - T_\infty) \tag{1.2}$$

where h is the convective heat transfer coefficient (W/m^2·K), T_s is the surface temperature and T_∞ is the ambient air temperature. An example is smoke and hot gases rising from burning furniture, heating the ceiling and upper walls and promoting rapid fire spread.

Radiation is the emission of heat energy as electromagnetic waves, which can ignite nearby objects without direct physical contact. The governing equation is given by the Stefan-Boltzmann law:

$$q = \epsilon\sigma(T^4 - T_\infty^4) \tag{1.3}$$

where ϵ is emissivity, σ is the Stefan-Boltzmann constant (5.67×10^{-8} W/m^2·K^4), and T and T_∞ represent the temperatures of the radiating and surrounding surfaces, respectively. For instance, heat radiating from a burning structure can ignite adjacent buildings or vegetation, leading to extensive fire spread.

Fig. 1.4 Heat transfer through conduction, convection, and radiation

Fires can be classified as either fuel-controlled or ventilation-controlled. **Fuel-controlled** fires occur when there is ample Oxygen available, and the fire's growth and intensity depend solely on the quantity and type of fuel present. Typically, these fires burn fiercely until fuel depletion occurs. In contrast, **ventilation-controlled** fires occur when the available oxygen supply limits the fire's intensity and growth rate. This often happens in enclosed spaces, where oxygen levels quickly diminish due to combustion. Ventilation-controlled fires may initially burn slower and produce significant smoke, but they pose a high risk of rapid intensification if fresh air is introduced suddenly, potentially causing flashover or backdraft conditions. Understanding the distinction between these two fire types is critical for effective firefighting and designing appropriate fire safety strategies.

1.3 Classification and category of fire

Fires are categorised according to the type of fuel that is ignited. Both the International Organization for Standardization (ISO) and the National Fire Protection Association (NFPA) provide widely recognised standards for classifying fires. Understanding these classifications is crucial in selecting the appropriate extinguishing methods.

The International Organization for Standardization has developed ISO 834-1999, a standard that classifies fires into distinct categories based on the nature of the fuel involved. This classification is particularly valuable in the context of fire suppression, especially when selecting appropriate extinguishing methods. The current version, ISO 3941:2007, which is the second edition of this standard, categorises fires into the following distinct classes:

- **Class A Fires (Solid Combustibles)**: These fires involve common combustible materials such as wood, paper, textiles, rubber, and plastics. Class A fires leave ash upon burning.

Extinguishers: Water-based extinguishers, foam extinguishers, or dry chemical powder extinguishers are suitable for Class A fires. For example, a fire in a paper storage room is best tackled using a water-based extinguisher as it cools the material below ignition temperature.

- **Class B Fires (Flammable Liquids)**: Class B fires involve flammable or combustible liquids like petrol, diesel, oil, solvents, paints, and alcohol.

Extinguishers: Foam extinguishers, dry chemical powder extinguishers, and carbon dioxide extinguishers are effective against Class B fires. For instance, a petrol fire at a fuel station requires a foam extinguisher as it creates a barrier that cuts off Oxygen.

- **Class C Fires (Gases)**: Fires involving combustible gases such as propane, butane, methane, and hydrogen fall under Class C.

Extinguishers: Dry chemical powder extinguishers are primarily used. These extinguishers interrupt the chemical reaction of combustion. For example, a propane leak causing ignition in a kitchen would require a dry powder extinguisher to suppress the fire.

- **Class D Fires (Metals)**: These fires involve combustible metals like magnesium, aluminium, titanium, and sodium.

Extinguishers: Special dry powder extinguishers are designed specifically for metal fires. For instance, a magnesium fire in a laboratory requires a specialised powder extinguisher that forms a crust over the metal, preventing oxygen contact.

- **Class E Fires (Electrical Equipment)**: Although not classified separately by NFPA (covered under Class C in NFPA), ISO classifies fires involving electrical equipment as Class E.

Extinguishers: Carbon dioxide extinguishers and dry powder extinguishers are used as they are non-conductive and safe to use on live electrical equipment. An example would be a fire caused by overheating electrical wiring, safely extinguished by CO_2.

- **Class F Fires (Cooking Oils and Fats)**: These fires involve cooking media such as vegetable oils and animal fats generally found in kitchens.

Extinguishers: Wet chemical extinguishers are specifically designed for cooking oil and fat fires. They create a cooling and saponification effect that prevents re-ignition. For example, a fire from overheated oil in a commercial kitchen fryer is safely managed by applying a wet chemical extinguisher.

Selecting the correct fire extinguisher based on the fire class is critical. Using the wrong extinguisher can exacerbate the situation. Comprehensive training and clear labeling of extinguishers according to ISO and NFPA classifications are fundamental to effective fire safety management. Beyond these conventional categories, industrial and offshore settings introduce unique fire classifications. Hydrocarbon fires, common in oil and gas facilities, differ significantly from conventional fires due to their intense heat release and rapid spread (Pradeepa and Chandrasekaran 2024). These fires manifest as pool fires, where flammable liquid spills ignite over a surface, or jet fires, where high-pressure fuel leaks combust in a torch-like manner (Quintiere 2006). Due to their severity, hydrocarbon fires require advanced fire suppression techniques, including high-expansion foams and deluge systems.

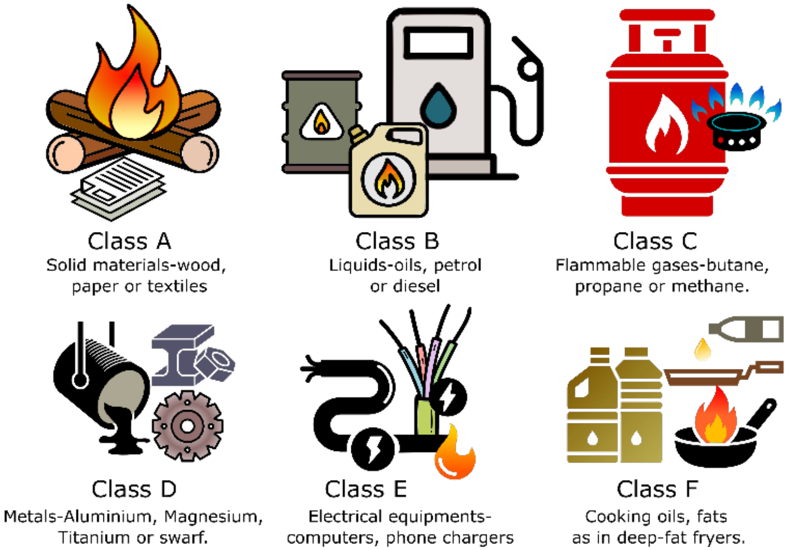

Fig. 1.5 Classification of fire

Classification of Industrial Fires: Pool Fires, Jet Fires, Flash Fires, and Fireballs

In the realm of industrial fire safety and risk assessment, understanding the different types of fires that can occur is crucial for effective prevention, control, and emergency response planning. Among the most significant classifications in industrial settings are

- pool fires
- jet fires
- flash fires, and
- fireballs.

These classifications are not arbitrary but are based on fundamental differences in how the fires originate, propagate, and impact their surroundings. This classification system is essential for risk assessment, consequence analysis, and the design of appropriate safety measures in process industries handling flammable materials.

Release Mechanism and Fuel State

The primary basis for classifying these industrial fires is the physical mechanism by which the flammable material is released and its physical state during combustion. Each type of fire involves a distinct release scenario that fundamentally shapes its subsequent behaviour. For instance, pool fires involve spilled liquids forming a reservoir, while jet fires result from pressurised releases creating directional flames with significant momentum. The physical state of the fuel, whether it's a liquid forming a pool, a pressurised gas creating a jet, or a vapour cloud dispersing in air, fundamentally determines the classification and behaviour of the resulting fire.

Ignition Timing and Sequence

Another critical factor in fire classification is the timing and sequence of ignition relative to the release of flammable material. In some scenarios, ignition occurs immediately upon release, while in others, there may be a delay during which the flammable material accumulates or disperses before encountering an ignition source. This timing significantly affects the resulting fire type and its consequences. For example, immediate ignition of a pressurised gas release typically results in a jet fire, while delayed ignition of a dispersed vapour cloud might lead to a flash fire or, under certain conditions, a fireball.

Flame Propagation and Combustion Dynamics

The way flames propagate through the fuel and the underlying combustion dynamics also form a basis for classification. Flash fires involve rapid flame propagation through a premixed vapor cloud, while pool fires exhibit more steady diffusion flames above a liquid surface. The combustion process in jet fires is characterised by turbulent diffusion in a high-velocity stream, creating unique flame characteristics. These differences in combustion dynamics directly impact the fire's duration, intensity, and potential for causing damage.

Pool Fires

A pool fire is defined as a turbulent diffusion fire burning above a horizontal pool of vaporising hydrocarbon fuel where the fuel has zero or low initial momentum. These fires typically form when a flammable liquid is spilled and accumulates on a flat surface, creating a reservoir or "pool" that, upon ignition, burns steadily as the liquid vaporises at the surface. The fire is sustained by the continuous evaporation of the liquid fuel, driven by heat feedback from the flames above. This type of fire represents a common hazard in facilities handling and storing flammable liquids, particularly in petrochemical plants, refineries, and fuel storage facilities.

Pool fires exhibit several distinctive characteristics that influence their hazard potential. The fire typically burns with visible flames that radiate heat and produce smoke, with the severity depending largely on the size of the liquid pool and the specific type of fuel involved. These fires can be categorised as either static, where the fire is contained within defined boundaries such as a bund or depression, or "running" fires that spread across a surface as the liquid flows. The burning rate in pool fires is primarily a function of the fuel's heat of combustion and the heat required for its vaporisation, with heat radiation typically dominating the burning rate for flames greater than 1 meter in diameter. This radiation field extends outward from the fire, creating hazard zones that must be considered in facility design and emergency planning.

Pool fires commonly occur in scenarios where containment of flammable liquids is breached. Typical examples include:

- Storage tank overfill events where liquid hydrocarbon spills into a containment bund and ignites
- Pipeline ruptures or leaks that allow liquid fuels to accumulate before finding an ignition source
- Tanker truck accidents where fuel spills onto roadways or parking areas

Jet Fires

A jet fire occurs when a flammable liquid or gas is ignited after its release from a pressurised, punctured vessel or pipe. The high pressure of the release generates a momentum-driven, directional flame that can extend considerable distances from the point of release. These fires are characterised by their concentrated nature and the significant kinetic energy involved in the release, which shapes the resulting flame structure and behaviour. Jet fires typically form when high-pressure systems containing flammable materials develop breaches, whether through equipment failure, physical damage, or operational errors, and the escaping material immediately encounters an ignition source.

Jet fires exhibit several distinctive features that make them particularly dangerous in industrial settings. The flame is typically long and narrow, with a high heat release rate concentrated in a specific direction. The length of the flame increases directly with the flow rate of the release, with a typical pressurised release of 8 kg/s potentially creating a flame extending up to 35 meters. Crosswinds can significantly affect the flame length, with increases in crosswind velocity generally leading to longer flames.

The heat flux from jet fires is typically about double that of pool fires of comparable size, making them more destructive to equipment and structures in their path. The duration of a jet fire is determined primarily by the release rate and the total capacity of the source, which influences emergency response strategies and the potential for escalation to affect adjacent equipment. Unlike pool fires, which may be relatively easy to contain, jet fires are often more challenging to extinguish because the fuel source is pressurised and directional.

Jet fires occur in various industrial contexts where pressurised flammable materials are handled:

- Ruptures in high-pressure gas pipelines with immediate ignition
- Leaks from pressure relief valves or vents that encounter ignition sources

- Failures of pressurised vessel connections or instrumentation points
- Compressor or pump seal failures in systems handling flammable gases or volatile liquids

Flash Fires

A flash fire is defined as the combustion of a flammable vapour and air mixture in which the flame passes through the mixture at subsonic velocity, such that negligible overpressure is generated. These fires occur when a cloud of flammable gas or vapour forms from a release, disperses to create a flammable mixture with air and subsequently encounters an ignition source. The key characteristic of flash fires is that they involve the combustion of premixed fuel and air within the flammable range, between the Lower Flammable Limit (LFL) and Upper Flammable Limit (UFL) of the substance.

The formation of flash fires typically involves a sequence of events: first, a release of flammable material creates a vapour cloud; second, this cloud disperses through atmospheric processes; and finally, the cloud encounters an ignition source within its flammable limits. This sequence explains why flash fires often occur some distance from the original release point, as the cloud may travel considerable distances before finding an ignition source.

Flash fires exhibit several distinctive behavioural characteristics. The flame spreads rapidly through the flammable portions of the vapour cloud, typically at speeds around 4-5 m/s, though this can vary based on fuel type and concentration. During a flash fire, the flame initially propagates through regions within the flammable limits, starting at the ignition point and moving both upwind and downwind. After consuming the flammable vapour, the flame extends upward in the form of a fire plume above the cloud.

The duration of a flash fire is very short, typically less than 3 seconds, with damage primarily caused by thermal radiation and, in enclosed spaces, oxygen depletion. Despite their brief duration, flash fires can produce intense heat fluxes of approximately 80 kW/m^2. While the overpressure effects are typically negligible compared to explosions, the thermal effects can be lethal to personnel caught within the flame envelope, with anyone present within the flash fire zone likely to suffer fatal burn injuries.

Flash fires occur in various industrial contexts, particularly in petrochemical facilities: