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Electric Arc-Induced Pyrolysis of Transformer Oil: A Pathway to Combustible Gas Generation, Fireball Formation, and the Challenge of Visual Scale Perception in Night-Time Incidents

Miltiadis Karazoupis*

Independent Researcher

***Corresponding Author**
Miltiadis Karazoupis Independent Researcher.

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Abstract

Power transformers are critical components in electrical grids, and their operational integrity is paramount. The mineral oil used within these transformers serves as both an insulator and a coolant. However, internal electrical faults, particularly high-energy arcing, can subject this oil to extreme thermal stress. This article investigates the phenomenon of pyrolysis in transformer oil initiated by electric arcs, typically resulting from fault conditions with voltages such as 25,000 Volts or higher within the equipment's operational context. It explores the mechanisms by which arc-induced high temperatures lead to the decomposition of insulating oil into various combustible gases, primarily hydrogen, acetylene, methane, and ethylene. The rapid generation and accumulation of these gases can cause a significant pressure rise within the transformer tank, potentially leading to tank rupture. Upon rupture and the subsequent release of the flammable gas mixture and atomized oil into the atmosphere, ignition by the arc or hot components can result in a catastrophic fireball and sustained fire. This review synthesizes existing literature on arc characteristics, oil pyrolysis chemistry, gas generation dynamics, pressure vessel failure, and combustion phenomena to demonstrate the credible pathway from an internal electric arc to a transformer fireball. Furthermore, it addresses the common misperception of fireball size when viewed through low-resolution, low-frame-rate night-time cameras, considering factors such as blooming, lens flare, and atmospheric refraction due to humidity, which can lead to an overestimation of the actual event scale. Understanding this entire sequence, including the nuances of visual evidence interpretation, is crucial for enhancing transformer design, safety protocols, diagnostic techniques like Dissolved Gas Analysis (DGA), and accurate post-incident analysis.

Keywords: Transformer Oil, Pyrolysis, Electric Arc, Fireball, Dissolved Gas Analysis (Dga), Transformer Explosion, Power Transformer Safety, Fault Gases, Visual Perception, Image Artifacts, Night-Time Recording

1. Introduction

Power transformers are indispensable assets in electrical power generation, transmission, and distribution systems, facilitating voltage transformation to appropriate levels for efficient energy transfer and consumption. The vast majority of these transformers utilize mineral oil as a primary insulating and cooling medium due to its excellent dielectric properties and heat dissipation capabilities [1]. Despite their robust design and high reliability, transformers are susceptible to internal faults. These faults can arise from various stresses, including electrical transients (e.g., lightning strikes, switching surges), dielectric degradation, mechanical issues, or overloading [2].

Among the most severe internal fault types is the occurrence of an electric arc. An arc is a sustained electrical discharge through a normally non-conductive medium, such as the insulating oil, characterized by very high current densities and extremely high temperatures [3]. Such arcing events can be initiated by insulation breakdown between windings, between windings and grounded parts, or within tap changers. The energy released by an electric arc within the confined environment of a transformer tank can lead to a rapid and violent sequence of events.

One of the immediate consequences of high-temperature arcing in oil is pyrolysis – the thermal decomposition of the oil's complex hydrocarbon molecules into simpler, often gaseous, compounds [4]. The generation of these gases, which are predominantly flammable (e.g., hydrogen, acetylene, methane, ethylene), leads to a significant increase in internal pressure. If this pressure exceeds the mechanical strength of the transformer tank, a catastrophic rupture can occur, expelling hot oil and flammable gases into the surrounding environment. The ignition of this dispersed fuel-air mixture, often by the initiating arc itself or by incandescent components, can result in a large fireball and subsequent pool fire, posing severe risks to personnel, adjacent equipment, and the environment [5].

The visual documentation of such incidents, particularly those occurring at night, often relies on surveillance systems like traffic cameras. However, the interpretation of fireball size and intensity from such footage can be problematic. Factors inherent in low-resolution, low-frame-rate digital imaging, compounded by night-time conditions and atmospheric effects like humidity-induced refraction, can lead to significant optical distortions, such as blooming and exaggerated flare, potentially resulting in an overestimation of the actual physical scale of the fireball [6].

This article aims to provide a comprehensive review of the processes leading from an electric arc in transformer oil to the formation of a fireball. It will detail the pyrolysis mechanisms, the characteristics of the gases produced, the dynamics of pressure buildup and tank rupture, and the conditions leading to ignition and fireball development. Furthermore, it will critically examine the factors that can influence the perceived size of such fireballs in typical night-time, low-quality camera recordings, highlighting the potential discrepancy between visual representation and physical reality.

2. Literature Review

The sequence of events from an internal electric arc in a power transformer to a potential fireball involves several interconnected physical and chemical phenomena. This review examines the existing body of knowledge concerning electric arc characteristics in insulating liquids, the pyrolysis of transformer oil, subsequent gas generation and pressure dynamics, fireball formation, and the challenges associated with the visual interpretation of such events from remote imaging systems.

2.1. Electric Arc Characteristics in Transformer Oil

An electric arc in liquid dielectrics like transformer oil is a complex plasma phenomenon. When the dielectric strength of the oil is exceeded, a conductive channel forms, leading to a high-current discharge [7]. The energy dissipated by the arc is a product of the arc voltage and current over time. Arc temperatures are exceptionally high; studies suggest that the core of an arc in oil can reach temperatures ranging from 8,000 K to over 20,000 K [3,8]. This intense localized heating is the primary driver for the subsequent pyrolysis of the surrounding oil. The arc voltage in a liquid is influenced by factors such as gap distance, current magnitude, and the properties of the liquid itself, including its decomposition products [9]. Research by highlights that the energy released during arcing faults is directly correlated with the severity of the damage and the volume of gas produced [5].

2.2. Pyrolysis of Transformer Oil and Gaseous Byproducts

Transformer oils are typically mineral-based, composed of complex mixtures of hydrocarbon molecules (paraffinic, naphthenic, and aromatic). When subjected to the extreme temperatures of an electric arc, these molecules undergo thermal cracking, or pyrolysis, breaking down into simpler, lower molecular weight gases. The composition of these gases is highly dependent on the temperature and energy of the fault [10].

- Low to Moderate Energy Faults (Overheating): At temperatures below 300°C, the primary decomposition gases are Methane (CH4) and Ethane (C2H6), with some Ethylene (C2H4) [11].
- Partial Discharges: These low-energy discharges primarily produce hydrogen (H_2) and some methane.
- High-Energy Arcing: At the very high temperatures associated with arcing (typically >700°C, and often much higher in the arc core), the dominant gases produced are Acetylene (C2H2) and Hydrogen (H2) [10,12]. Ethylene and methane are also formed in significant quantities. The presence of acetylene is widely considered a key indicator of high-energy arcing within a transformer [13].

If cellulosic insulation (e.g., paper, pressboard) is involved in the fault and exposed to high temperatures, carbon monoxide (CO) and carbon dioxide (CO_2) are also generated, alongside the hydrocarbon gases [14]. The rate of gas production is directly related to the arc energy; higher energy faults lead to more rapid and voluminous gas generation [15].

2.3. Gas Generation Dynamics, Pressure Buildup, and Tank Rupture

The rapid formation of gases within the confined volume of a transformer tank leads to a swift increase in internal pressure. The oil, due to its inertia, initially resists the expansion of the gas bubble formed by the arc, causing a very rapid pressure peak (dynamic pressure rise) before the system reaches a more quasi-static pressure condition if the fault persists [16]. Theoretical models and experimental studies have been developed to predict the pressure rise based on arc energy and transformer geometry [17,18].

If the internal pressure exceeds the ultimate tensile strength of the transformer tank or its components (e.g., bushings, relief devices), a mechanical rupture will occur. This rupture can be violent, leading to the ejection of hot oil, gas, and potentially transformer components [5]. The design of pressure relief devices is critical in mitigating overpressure, but very rapid pressure increases from high-energy arcs can sometimes overwhelm these devices or lead to tank failure before they can fully operate [19].

2.4. Ignition and Fireball Formation

Upon tank rupture, the superheated, flammable gas mixture (rich in H_2, C_2H_2, CH_4, C_2H_4) and atomized oil are expelled into the atmosphere. If an ignition source is present, which is highly probable given the initiating arc itself or incandescent metal parts, this fuel-air mixture can ignite. The resulting combustion can manifest as a fireball, particularly if the release is rapid and the ignition is immediate. This phenomenon shares characteristics with a Boiling Liquid Expanding Vapor Explosion (BLEVE) or a Vapor Cloud Explosion (VCE), depending on the state of the oil and the nature of the dispersion and ignition [20].

The size and intensity of the fireball depend on the quantity and type of flammable material released, the energy of the release, the degree of fuel-air mixing, and ambient conditions [21]. Studies on industrial accidents have shown that the combustion of such clouds can produce significant thermal radiation and overpressure effects [22]. The ejected oil can also form pool fires or spray fires, sustaining the combustion event long after the initial fireball.

2.5. Visual Perception of Fireballs and Recording Artifacts in Night-Time Conditions

The visual recording of transformer failures, especially fireballs occurring at night, is often accomplished using security or traffic cameras. These cameras typically have limitations in terms of resolution, frame rate, and dynamic range [23]. When recording highly luminous events like fireballs against a dark background, several optical and sensor-related artifacts can distort the perceived size and nature of the event:

- Blooming and Smearing: Intense light sources can cause charge to overflow from saturated pixels to adjacent pixels in CCD or CMOS sensors, making the light source appear larger and more diffuse than it is [24].
- Lens Flare: Internal reflections within the camera lens system can create streaks, halos, or geometric patterns that are not part of the actual scene, exaggerating the extent of the light.
- Low Frame Rate: Low frame rates (e.g., common in surveillance footage) may not capture the rapid evolution of the fireball accurately, potentially missing peak intensity or leading to motion blur that alters perceived size.
- Atmospheric Refraction and Scattering: Humidity, dust, or smoke in the atmosphere can refract and scatter light, particularly from an intense source. At night, high humidity can cause light to "glow" or appear larger due to scattering by water droplets [25]. This effect can be exacerbated by the bright, broad-spectrum light of a fireball.
- Automatic Gain Control (AGC): Camera AGC can increase the brightness of the overall scene in low light, which can further amplify the blooming effect around very bright sources.

Research in image processing and forensic analysis of video footage acknowledges these distortions. discuss the challenges of analyzing CCTV footage for accident reconstruction, noting how environmental conditions and camera limitations affect image quality [6]. Therefore, direct estimation of a fireball's physical dimensions from unprocessed night-time surveillance footage without accounting for these artifacts is likely to be inaccurate and often leads to an overestimation of its true scale.

This literature review underscores the well-established link between electric arcing in transformer oil and the potential for pyrolysis, gas generation, tank rupture, and subsequent fireball. It also highlights the important caveat that visual evidence of such events, particularly from non-specialized night-time camera systems, must be interpreted with caution due to significant potential for optical and recording distortions.

3. Research Questions

This review seeks to synthesize existing knowledge to address the following key research questions concerning electric arc-induced pyrolysis in transformer oil and the subsequent formation of fireballs, including the challenges in visually assessing such events:

1. What are the primary physical and chemical mechanisms by which a high-energy electric arc, such as one potentially arising from a 25,000 Volt fault condition within an oil-filled power transformer, initiates and sustains the pyrolysis of the insulating mineral oil?
2. What is the characteristic composition and relative abundance of key combustible gases (e.g., hydrogen, acetylene, methane, ethylene) produced during the arc-induced pyrolysis of transformer oil, and how do these specific gases contribute to the flammability and explosive potential of the released mixture?
3. How does the rapid generation of pyrolysis gases lead to critical pressure increases within a sealed transformer tank, what factors influence the likelihood of tank rupture, and what are the typical modes of failure?
4. Under what conditions does the ignition of the expelled gas and atomized oil mixture occur following tank rupture, leading to the formation of a fireball, and what are the primary factors determining its initial characteristics (e.g., size, duration, radiative heat)?
5. How do optical phenomena (e.g., blooming, lens flare) and limitations of typical surveillance camera systems (e.g., low resolution, low frame rate), particularly under night-time conditions and in the presence of atmospheric humidity, contribute to a potential discrepancy between the observed or recorded size of a transformer fireball and its actual physical dimensions?

4. Methodology and Results

4.1. Methodology

This scholarly article employs a comprehensive literature review methodology to investigate the phenomenon of electric arc-induced pyrolysis in transformer oil leading to fireball formation, and the associated challenges in visual scale perception. The research process involved several stages:

1. Literature Search Strategy: A systematic search of academic databases and relevant industry publications was conducted. Key databases included Google Scholar, IEEE Xplore, ScienceDirect, Scopus, and Web of Science. Search terms were used in various combinations, including: "transformer oil pyrolysis," "electric arc in oil," "transformer explosion," "transformer fire," "dissolved gas analysis," "DGA," "acetylene generation," "hydrogen in transformers," "transformer tank rupture," "pressure buildup transformer," "fireball formation," "BLEVE," "vapor cloud explosion," "CCTV image distortion," "night-time camera artifacts," "blooming effect," "lens flare," and "visual perception low resolution." The search was primarily focused on peer-reviewed journal articles, conference proceedings, industry standards (e.g.,

IEEE, IEC, Cigré), and authoritative technical reports.

4.2. Inclusion and Exclusion Criteria: Studies were included if they directly addressed:

- The physics of electric arcs in liquid dielectrics.
- The thermal decomposition (pyrolysis) of mineral insulating oils.
- The types and generation rates of gases produced by faults in transformers.
- The mechanics of pressure buildup and tank failure in transformers.
- The ignition and combustion characteristics of gases and oil mists released from transformers.
- The principles of Dissolved Gas Analysis (DGA) and its interpretation.
- Optical effects, camera limitations, and image artifacts relevant to recording luminous events at night.

Studies were excluded if they were not available in English, were of insufficient academic rigor (e.g., non-technical articles, opinion pieces without empirical backing), or were focused on unrelated aspects of transformer operation or oil degradation (e.g., slow aging without catastrophic failure).

4.3. Data Extraction and Synthesis: Relevant information from the selected literature was extracted and categorized according to the research questions. This involved identifying key findings, theoretical models, experimental results, and case study analyses. The information was then synthesized to build a coherent narrative addressing each research question, highlighting areas of consensus, identifying knowledge gaps, and noting any conflicting findings in the literature.

4.4. Citation Management: All sources were managed using bibliographic software, and citations within the text and the reference list were formatted according to the Harvard referencing style.

5. Results

The synthesis of the reviewed literature provides the following results, structured around the research questions:

5.1. Mechanisms of Arc-Induced Pyrolysis

The literature confirms that a high-energy electric arc in transformer oil acts as an intense, localized heat source with temperatures often exceeding 3,000°C and potentially reaching up to 20,000°C [3,8]. This extreme thermal energy is directly transferred to the surrounding oil. Transformer mineral oil, being composed of long-chain hydrocarbon molecules, undergoes rapid thermal cracking (pyrolysis) when subjected to temperatures above its decomposition threshold (around 200°C, with significant decomposition occurring at much higher temperatures typical of arcs) [4]. The high temperatures break the C-C and C-H bonds in the oil molecules, leading to the formation of smaller, gaseous molecules. The energy of the arc (a function of voltage, current, and duration) directly dictates the volume of oil pyrolyzed and the rate of gas generation [5]. Even at 25,000 Volts, if sufficient current flows, the arc power can be substantial enough to cause significant and rapid pyrolysis.

5.2. Composition of Combustible Gases and Flammability

A consistent finding across numerous studies and standards [10,12,4] is that high-energy arcing in transformer oil predominantly produces:

- Hydrogen (H2): A major component, highly flammable with a wide flammability range (4-75% by volume in air) and very low ignition energy.
- Acetylene (C2H2): Considered a key signature gas for high-energy arcing. It is also highly flammable (2.5-82% by volume in air) and can decompose explosively even in the absence of air under certain conditions.
- Methane (CH4): Flammable (5-15% by volume in air).
- Ethylene (C2H4): Flammable (2.7-36% by volume in air).

Lesser amounts of ethane (C_2H_6) and other heavier hydrocarbon gases may also be present.

- Ethane (C2H6)
- Carbon Monoxide (CO)
- Carbon Dioxide (CO2)

If cellulosic insulation is involved, carbon monoxide (CO) (flammable, 12.5-74% in air) and carbon dioxide (CO_2) are also produced [14]. The high concentrations of H_2 and C_2H_2, in particular, create a highly volatile and easily ignitable gas mixture. The combined flammability characteristics of these gases mean that the mixture released from a ruptured transformer can ignite readily and burn vigorously.

5.3. Pressure Buildup, Tank Rupture, and Failure Modes

The rapid generation of these gases in the confined space of a transformer tank leads to a steep pressure increase. The initial phase involves the formation of a gas bubble that expands against the inertia of the surrounding oil, creating a dynamic pressure wave [16]. If the arc continues, the quasi-static pressure builds. Literature indicates that pressures can rise to levels exceeding the mechanical withstand capability of the tank structure, seams, or ancillary components like bushings and pressure relief devices [17,18].

Failure modes include:

- Weld seam rupture.
- Tank wall bulging and tearing.
- Expulsion of bushings or other accessories.
- Catastrophic tank explosion.

The speed of pressure rise in high-energy arcing events can be so rapid that standard pressure relief devices may not have sufficient time or capacity to vent the pressure effectively before structural failure occurs [19].

Ignition Conditions and Fireball Formation

Following tank rupture, the mixture of hot, flammable gases and atomized oil is forcefully ejected. Ignition is highly probable due to:

- The initiating electric arc itself, which may still be active or re-strike.
- Incandescent metal particles or surfaces heated by the arc.
- Static discharge from the rapidly expanding, turbulent cloud.

Once ignited, the rapid combustion of the dispersed fuel-air mixture results in a fireball [20]. The characteristics of the fireball (size, duration, heat radiation) are determined by the total mass of flammable material released, the energy content of the gases, the efficiency of mixing with ambient air, and the speed of the release [21] . The event often transitions into a sustained pool fire if a significant quantity of oil is released and ignited on the ground or surrounding structures.

5.4. Discrepancy Between Observed and Actual Fireball Size due to Visual Artifacts

The literature on digital image processing, optical physics, and forensic video analysis confirms that night-time recordings of highly luminous events by standard surveillance cameras are prone to significant distortions that can lead to an overestimation of the event's physical scale:

- Blooming and Smearing: Saturated pixels in the camera sensor cause the light to "bleed" into adjacent pixels, making the bright area appear significantly larger and more diffuse [24]. This is a very common artifact with intense light sources like fireballs against a dark background.
- Lens Flare: Internal reflections within the lens assembly create non-existent light patterns (halos, streaks) that expand the perceived area of luminosity.
- Low Resolution and Compression: These factors can reduce image sharpness and detail, causing bright areas to blur and appear larger.
- Low Frame Rate: Can lead to motion blur if the fireball is rapidly evolving or moving, further exaggerating its apparent size in individual frames or making its dynamic behavior difficult to assess accurately.
- Atmospheric Effects: High humidity, common at night, can cause significant scattering and refraction of light from an intense source, creating a "glow" or halo effect that expands the perceived boundaries of the fireball [25]. This is particularly relevant for distant observations.
- Automatic Gain Control (AGC): In low-light conditions, AGC boosts the signal, which can amplify the visual impact of blooming and flare around bright objects.

Studies like those by Robertson emphasize the need for careful calibration and understanding of camera characteristics and environmental conditions when interpreting such footage for quantitative analysis [3,6]. Without specialized photometric equipment or advanced image processing techniques to correct for these artifacts, direct visual estimation of fireball size from typical night-time traffic or security camera footage is unreliable and likely to yield an exaggerated result compared to the actual physical dimensions of the combusting zone.

6. Discussion

The synthesis of existing literature robustly supports the chain of events from a high-energy electric arc within an oil-filled power transformer to the pyrolysis of insulating oil, the generation of combustible gases, subsequent tank rupture due to overpressure, and the potential formation of a catastrophic fireball. This review has addressed the fundamental mechanisms, the nature of the hazardous gases produced, the dynamics of pressure buildup and tank failure, and the conditions leading to fireball ignition. Furthermore, a critical aspect highlighted is the challenge in accurately assessing the scale of such fireballs from typical night-time surveillance footage (RQ5), which has significant implications for incident analysis and public perception.

6.1. The Inevitability of Pyrolysis and Gas Generation from High-Energy Arcs

The physics of electric arcs in liquids, characterized by extremely high temperatures, makes the pyrolysis of transformer oil an almost inevitable consequence of such faults [3]. The energy delivered by an arc, even from a system with a nominal voltage like 25,000 V if coupled with sufficient fault current, is more than adequate to break down hydrocarbon molecules. The consistent identification of acetylene (C_2H_2) and hydrogen (H_2) as key gases in Dissolved Gas Analysis (DGA) following severe faults is a testament to the high temperatures achieved and the pyrolytic processes at play [10,12]. These gases are not only diagnostic indicators but also primary contributors to the subsequent explosion and fire hazard. The flammability characteristics of this gas mixture, particularly the wide flammability limits and low ignition energy of hydrogen and acetylene, mean that a released cloud is exceptionally prone to ignition.

6.2. Pressure Dynamics and the Challenge of Mitigation

The rapid rate of gas generation from arc-induced pyrolysis presents a formidable challenge to transformer tank integrity. While pressure relief devices are standard components, their efficacy can be overwhelmed by the sheer speed and volume of gas produced in high-energy arcing events [19,18]. This underscores the importance of not only robust tank design but also advanced fault detection and rapid de-energization systems to limit arc energy and duration, thereby reducing gas production. The transition from a dynamic pressure wave to a quasi-static pressure buildup, as described by Bérubé, highlights the complex mechanical stresses the tank endures [16].

6.3. Fireball Formation: A Credible Consequence

Given the expulsion of a highly flammable, pre-heated gas and oil mist mixture into an environment where an ignition source (the arc itself or hot components) is almost certainly present, fireball formation is a highly credible outcome of a catastrophic transformer failure [20]. The destructive potential of such fireballs, through thermal radiation and potential overpressure, necessitates careful consideration in substation design, safety zoning, and emergency response planning. The subsequent risk of sustained pool fires further compounds the hazard.

6.4. The Deceptive Nature of Night-Time Visual Evidence

A crucial contribution of this review is the emphasis on the unreliability of casual visual estimations of fireball size from typical night-time surveillance footage, such as that from traffic cameras. The confluence of optical artifacts like blooming and lens flare, sensor limitations, low frame rates, and atmospheric conditions (especially humidity) can create a visual impression of a fireball that is significantly larger and more dramatic than the actual physical scale of the combusting fuel-air cloud [24,25,1]. This has several important implications:

- Incident Investigation: Relying solely on uncalibrated visual footage for determining the energy of the event or the extent of the initial hazard can be misleading. A seemingly massive fireball on a low-quality video might not directly correlate with an exceptionally large quantity of fuel released, but rather with the optical response of the camera system to an intensely luminous event.
- Public Perception and Media Reporting: Dramatic footage can lead to public alarm and potentially inaccurate media reporting regarding the magnitude of an incident if the limitations of the recording are not understood.
- Engineering Analysis: For engineers and safety analysts, it is vital to seek corroborating evidence (e.g., extent of thermal damage, pressure calculations based on fault energy, DGA results prior to failure if available) rather than relying on apparent visual size from compromised footage. Computational Fluid Dynamics (CFD) modeling of the gas release and combustion, informed by estimated fault energy, can provide a more physically grounded estimation of potential fireball dimensions than direct interpretation of distorted video.

While the actual fireball from a transformer explosion is undeniably a severe and dangerous event, understanding these visual artifacts is key to objective analysis and preventing the misinterpretation of its scale. Future research could involve controlled experiments to quantify the extent of these visual distortions for typical surveillance camera setups when recording combustion events of known sizes under various atmospheric conditions.

This discussion highlights that while the core phenomena of arc-induced pyrolysis and subsequent fireball formation are well-understood scientifically, the practical interpretation of real-world incidents, especially when relying on non-ideal visual data, requires careful consideration of confounding factors.

7. Conclusion

This review has systematically examined the pathway from the initiation of a high-energy electric arc in oil-filled power transformers to the potential formation of a destructive fireball. The evidence drawn from extensive literature confirms that:

1. Electric arcs, such as those that can occur during fault conditions (even at system voltages like 25,000V if fault currents are significant), generate extremely high temperatures within the transformer oil. These temperatures are far in excess of those required to initiate rapid pyrolysis of the mineral insulating oil.
2. The pyrolysis process decomposes the oil into a mixture of combustible gases, with hydrogen and acetylene being key indicators and major constituents of high-energy arc faults. Methane, ethylene, and, if cellulosic insulation is involved, carbon monoxide, also contribute to the flammability of the mixture.
3. The rapid and voluminous generation of these gases within the confined transformer tank leads to a significant and swift increase in internal pressure. This pressure can exceed the mechanical withstand capability of the tank, leading to rupture and the violent expulsion of hot gases and atomized oil.
4. The ignition of this flammable mixture upon release into the atmosphere, typically by the arc itself or hot components, can result in a fireball, posing substantial thermal and potential overpressure hazards.
5. A critical, often overlooked, aspect is the interpretation of visual evidence of such fireballs, particularly from night-time surveillance footage (e.g., traffic cameras). Optical artifacts such as blooming and lens flare, coupled with camera system limitations (low resolution, low frame rate) and atmospheric conditions like humidity, can lead to a significant overestimation of the fireball's actual physical size. This discrepancy between perceived and actual scale is vital to acknowledge for accurate incident analysis and to avoid misjudgment of the event's magnitude based solely on distorted visual recordings.

The sequence of arc-induced pyrolysis, gas generation, pressure buildup, tank rupture, and subsequent fireball is a well-understood, credible failure mode for oil-filled power transformers. Understanding these phenomena is paramount for the continuous improvement of transformer design, the implementation of effective diagnostic and protection schemes (like DGA and rapid de-energization), the development of robust safety protocols in substations, and the accurate forensic analysis of transformer failures. Future work should continue to refine predictive models for gas generation and pressure dynamics, as well as develop methodologies for more accurately interpreting visual recordings of such incidents to account for known optical and systemic distortions. This holistic understanding is essential for mitigating the risks associated with these critical components of electrical power infrastructure.

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