VIVA-TECH IJRI
ANNUAL RESEARCH JOURNAL
VIVA-TECH INTERNATIONAL JOURNAL FOR RESEARCH AND INNOVATION
ANNUAL RESEARCH JOURNAL
ISSN(ONLINE): 2581-7280

Sound Waves vs. Flames: A Comprehensive Review on Acoustic Fire Extinguisher

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Abstract : *This review explores the potential of low-frequency acoustic technology as an innovative solution for fire suppression. By analyzing key studies, it evaluates the mechanisms, methodologies, and applications proposed by various researchers. Low-frequency sound waves, operating within the 30-60 Hz range, have demonstrated the ability to disrupt combustion dynamics and extinguish fires effectively. This paper reviews the findings, challenges, and advancements in this field, concluding that acoustic fire suppression is a feasible and promising approach for modern fire safety.*

Keywords *– Acoustic fire extinguisher, Class A fires, Class E fires, data centres, energy efficiency, environmentally friendly, low-frequency sound waves, non-invasive solution, residue-free technology, sustainable fire safety*

1. INTRODUCTION

Fire suppression is a critical safety requirement across industries, particularly in environments where traditional methods such as water, foam, or chemicals may cause significant collateral damage or are unsuitable [1]. Traditional fire extinguishers often leave residues, pose environmental risks, or fail to protect sensitive environments like data centres. Recent advancements in acoustic technologies suggest an innovative approach to addressing these limitations. By leveraging low-frequency sound waves to disrupt combustion, acoustic fire suppression offers a non-invasive, residue-free, and environmentally friendly alternative [2]. This paper reviews the progress in the field, focusing on methodologies, results, and challenges presented by researchers working on acoustic fire suppression technologies.

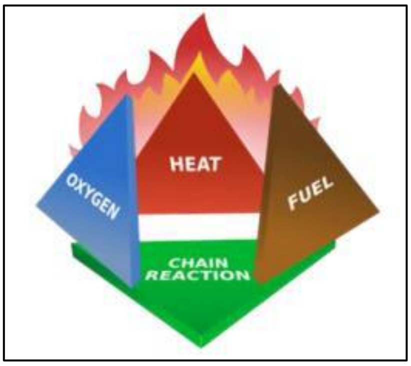

Fig.1 Flame tetrahedron [Safeopedia]

2. LITERATURE REVIEW

The literature explores the use of acoustic technologies for fire extinguishing and related innovations. J. Wilk-Jakubowski et al. [1] reviewed experimental attempts using low-frequency acoustic waves for flame extinguishment, while X. Shi et al. [2] studied their effect on ethanol pool fires. V. Loboichenko et al. [3] examined additional applications of acoustic waves for flame suppression. Qin et al. [4] focused on acoustic tomography for temperature field reconstruction in fire scenarios. S. Digiesi et al. [5] introduced the T-Fire system for truck fire monitoring. J. Erkmen et al. [6] studied fire-retardant insulation materials, while O. Shcherbak et al. [7] investigated environmental impacts of fire-fighting additives. Z. Su et al. [8] explored the response of flames to low-frequency acoustic fields. X. Li et al. [9] assessed fire extinguishing systems for liquor warehouses. N. A. Rizani et al. [10] developed a mobile-based fire extinguisher count system. Zenghui Guo et al. [11] studied fire suppression using ABC powder. J. L. González-Velázquez et al. [12] analyzed fire extinguisher failures, and Faix Awae and Paranyu Chareonmark [13] focused on optimal frequencies for acoustic extinguishing. P. Stawczyk et al. [14] explored controlling acoustic extinguishers with neural networks. These studies highlight the integration of acoustic waves in fire safety technologies.

3. CORE INSIGHTS ON ACOUSTIC FIRE SUPPRESION

3.1 Research and Analysis

The portable fire extinguisher market has shown significant growth, driven by the increasing number of fire incidents and the rising demand for advanced fire suppression systems [3]. According to industry data, the global market size for portable fire extinguishers is expected to reach $15.6 billion by 2026, growing at a CAGR of 12.8% [4]. Despite this growth, traditional extinguishers dominate the market, with water, foam, and chemical-based options being the most common. However, end-user confidence in these methods is declining due to their limitations in sensitive environments. This gap presents an opportunity for innovative solutions like acoustic fire extinguishers [5].

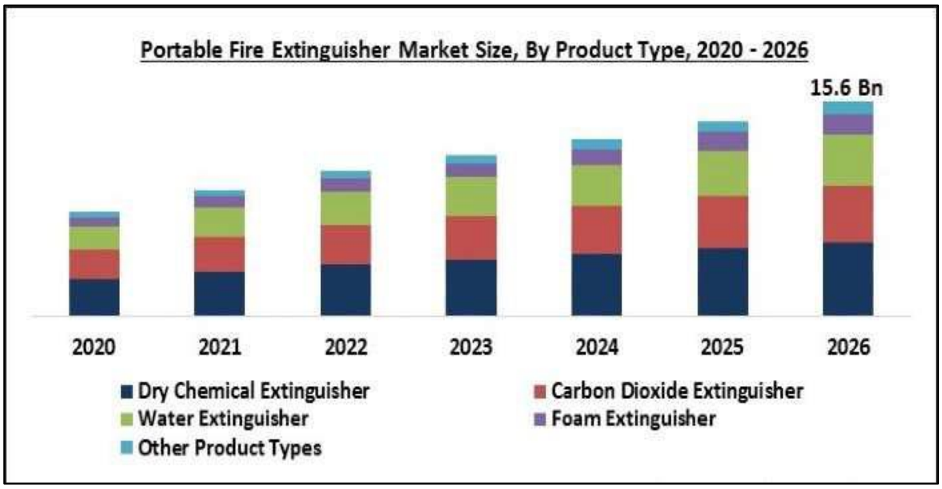

Fig.2 Market size data of portable fire extinguisher [KBV Research]

3.2 Sound Waves

Mechanical vibrations that propagate through a medium such as air, water, or solids are known as sound waves. They create alternating regions of compression and rarefaction, perceived as sound. The waveform of sound depicts pressure variations, with amplitude indicating loudness and frequency determining pitch. Human-perceivable sound ranges from 20 Hz to 20,000 Hz [6]. The interaction of sound waves with materials can influence combustion by altering air velocity and pressure near flames, making them an effective tool for fire suppression in specific frequency ranges [7].

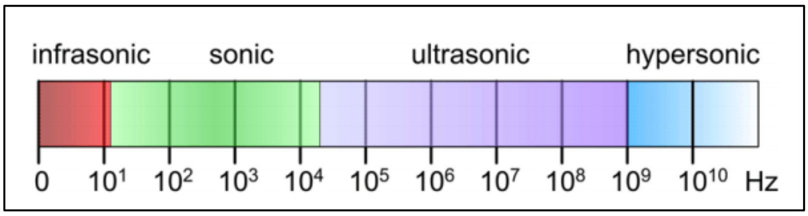

Fig.3 Frequency range of sound wave [ResearchGate]

3.3 **S**ound-Flame interactions & using sound wave as flame extinguisher

By altering the air velocity and pressure at the flame's boundary, sound waves affect the air-fuel ratio, increase convective heat transfer, and lower the flame temperature, leading to flame suppression [8]. This phenomenon is similar to a flame blow-off. Pressure fluctuations caused by sound waves create significant temperature changes, which, along with combustion instabilities, can extinguish the flame. The optimal frequency for effective suppression is around 60 Hz, as determined by experimental studies [9].

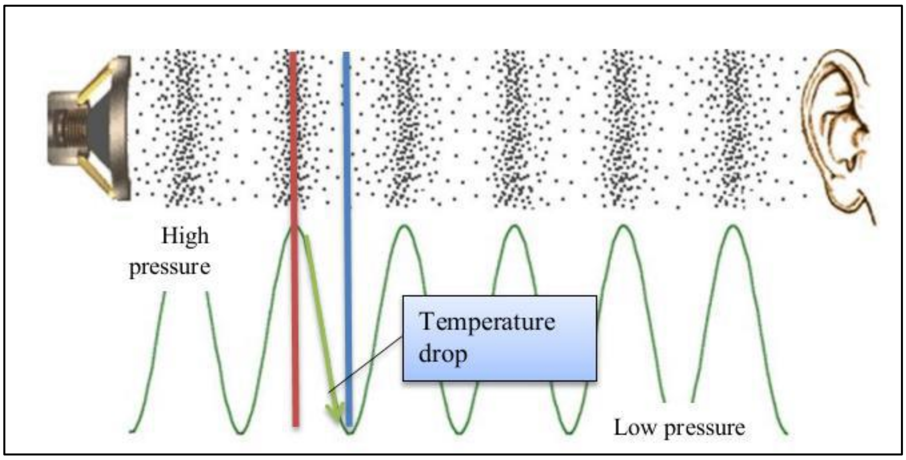

Fig.4 The physiology of sound [ResearchGate]

3.4 Fire Classes & Approximate Frequencies

Class A (Organic Solids)	Class B & Class C (Flammable Liquids & Gases)	Class E (Electric Fires)	Class D (Combustible Metals)	Class F (Fats & Oils)
• **Materials :** Wood, paper, cloth, rubber & plastics. • **Frequency Range :** 30 – 60 Hz	• **Materials :** Gasoline, oil, alcohol, and other flammable liquids or vapors. • **Frequency Range :** 40 – 70 Hz	• **Materials :** Electrical equipment such as computers, appliances and wiring. • **Frequency Range :** 50 – 80 Hz	• **Materials :** Magnesium, titanium, potassium, and other metals. • **Frequency Range :** Cannot be specified	• **Materials :** Cooking oils, grease & fats. • **Frequency Range :** 60 – 80 Hz

Fig.5 Classes of fires with approximate suppression frequencies

3.5 Characteristic of Acoustic Fire Extinguisher

- No residue : Acoustic extinguishers use sound waves, leaving no physical residue. This makes them ideal for clean environments like data centers and laboratories [10].
- Less damage to surroundings : Acoustic extinguishers do not release water, foam, or chemicals. They prevent damage to sensitive equipment and surroundings.
- Nontoxic : Sound waves are harmless to humans and the environment. This makes the device safe for homes, hospitals, and other sensitive areas [11].
- No expiration date : Without chemicals, acoustic extinguishers do not expire. Their electronic and mechanical parts require minimal maintenance.
- No refilling date : No consumables mean no refilling is needed. This reduces maintenance costs and ensures readiness for use [12].

4. Conclusion

4.1 Results

- The reviewed studies confirm that low-frequency acoustic waves (30-60 Hz) are effective in destabilizing flames and extinguishing Class A and Class E fires [13].

- Market analysis reveals strong demand for non-invasive fire suppression technologies, highlighting the feasibility of introducing this innovative system.
- Acoustic suppression systems provide a residue-free and environmentally friendly alternative, making them suitable for sensitive environments such as electrical rooms and data centres [14].

4.2 Discussion

- The proposed system is an innovative solution that addresses safety and environmental concerns where traditional methods may fail.
- Challenges remain in optimizing wave propagation over larger distances and ensuring precision targeting. Addressing these issues will require further experimental studies and technological advancements.
- This concept lays the groundwork for transforming fire safety protocols across industries, with scalability and field testing as future priorities.
- Additional research on cost efficiency, practical implementation, and automation integration is needed to realize its full potential.
- The integration of real-time monitoring systems, such as Acoustic CT, has improved understanding and accuracy in fire suppression efforts.

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