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THE UTILIZATION OF ACOUSTIC WAVES IN FIRE SUPPRESSION AND PREVENTION

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Abstract
The following paper examines the influence of acoustic waves on the behaviour of flames generated by various fuels. For the purposes of this investigation, a number of experiments were carried out using a specially constructed laboratory stand. This stand consisted of an acoustic waves frequency generator, an amplifier, and a low frequency speaker connected to the channel, upon which the waves were transmitted. The flames generated by various fossil fuels: gasoline, diesel oil and natural gas were exposed to the acoustic waves. The results of the experiment identified the critical sound pressure levels needed to extinguish various types of flames. These results may prove to be useful in the future construction of fire prevention systems at industrial facilities.

1. Introduction

Fire can be considered as one of the most serious safety problems in today's world. The onset of a fire during any production process may lead to substantial material losses. More importantly, a fire may seriously affect the health of workers, and may even lead to the loss of their lives. Hence, every company which cares about its own business should pay more attention to fire safety and prevention.

There are a number of proven and effective automatic fixed fire suppression systems utilising various extinguishing substances. These include, for example: water mist, neutral gases, foam, or systems used in server rooms based on reducing the oxygen concentration in the air which is needed for combustion [8, 9]. These methods have many advantages as well as some disadvantages. They certainly contribute to the suppression or complete extinction of fire. However, some media such as water or foam can cause damage, especially when coming into contact with some electrical equipment.

The fire can be extinguished in several ways [10]:

- by physical separation of the combustible material from fire,
- by closing off the supply of oxygen,
- by reduction of the temperature of the combustible material or fire,
- by using chemicals that weaken the combustion process.

Acoustic waves are a brand new and currently unused approach in the field of fire fighting. This approach is non-invasive in nature, meaning it does no damage to non-living matter. In the case of acoustic waves, the principle of quenching operation is based on rapid changes in the pressure. That pressure oscillations affect the flame structure and contribute to its wrenching, weakening, and finally to the extinction [3, 4, 11]. Acoustic waves are a brand new and currently unused approach in the field of fire fighting. This approach is non-invasive in nature, which means it does no damage to non-living matter. In the case of acoustic waves, the principle of quenching operation is based on rapid changes in the acoustic pressure. That pressure oscillations affect the flame structure and contribute to its wrenching, weakening, and finally to the extinction [3, 4, 11]. Another important parameter characterising acoustic waves is frequency. Previous works in the field revealed that low-frequency waves (30–50 Hz) are the most effective in quenching of flames [1–7, 11]. Also, power of the speaker should be regarded as a parameter characterising acoustic waves. All these parameters are discussed in the further part of the article.

1.1. Fixed fire suppression systems

Polish law clearly defines which objects should be protected by fixed fire suppression systems [7]. These include:

- archives designated by the Supreme Director of State Archives;
- museums and monuments designated by the General Conservator of Monuments in consultation with the Chief Commander of the State Fire Service;
- electronic data processing centres of national importance.

In addition, the use of fixed automatic water-extinguishing installation are required in buildings classified as ZL I (Polish Category of Threat to People) and buildings with a sufficiently large area [7]. Therefore, in most cases Polish entrepreneurs are not obligated to install similar systems. However, it does not exclude the profitability of such an investment.

Fixed fire suppression systems are nothing more than automatic systems designed to quench fire with the help of extinguishing medium. As previously mentioned, a customer can choose between: water based systems (sprinklers, drenchers, water mist), gas systems (inergen, FM-200, CEA 410, CO_2) and protective systems based on inerting (constant reduction of oxygen in combustion zone) which in fact do not serve to extinguish fire but to prevent it [8]. Currently, the same effects can be reached by the system based on acoustic waves. Properly designed sensor-based automated system employing low-frequency sound field acting on a source of fire should successfully extinguish it, without leaving any signs of damage.

1.2. Acoustic waves as an extinguishing agent

The study of the flame extinction process with utilizing acoustic waves is an issue rarely undertaken in Poland [3, 4, 6, 11]. More advanced research can be found in works elaborated abroad, however, still related to fundamental aspects of the process.

The work of McKinney and Dunn-Rankin [5] examined the acoustically-driven extinction of methanol. The flame was produced using a specially designed burner coupled with a generator of methanol droplets. After ignition the flame was subjected to the acoustic waves outgoing from a resonator tube. The power of flame was 1000 W. The research proved that the sound pressure required to extinguish the flame grew with the increase of the frequency.

The latest research in this field, conducted by Friedman and Stoliarov [2], showed similar results. In their work, flames of various alkanes (pentane, hexane, heptane and octane) and JP-8 rocket engines fuel were exposed to the acoustic waves. Flames were created using fuel-laden wicks. Powers of those flames were much lower, ranging from 1 to 5 W. Tests were carried out for frequency of 30–50 Hz, and the sound pressure, required to extinguish the flame, did not exceed 50 Pa.

In the present study similar output parameters of the acoustic waves were adopted. However, the research was conducted for the flames characterised by much higher powers.

2. Experimental procedure

2.1. Laboratory stand

Scheme of the experimental setup is presented in the Figs. 1–3.

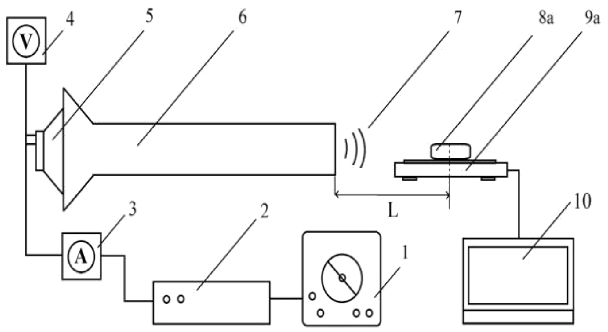

Fig. 1. Scheme of the experimental setup for the liquid fuels extinction [4].

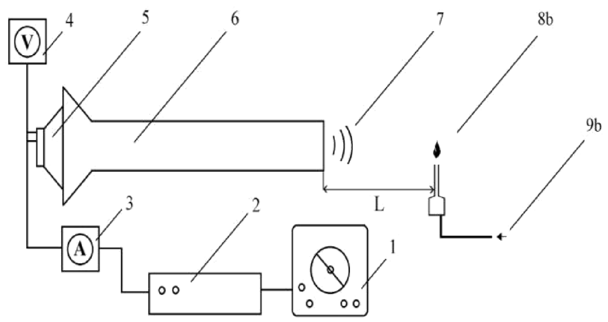

Fig. 2. Scheme of the experimental setup for the natural gas extinction [4].

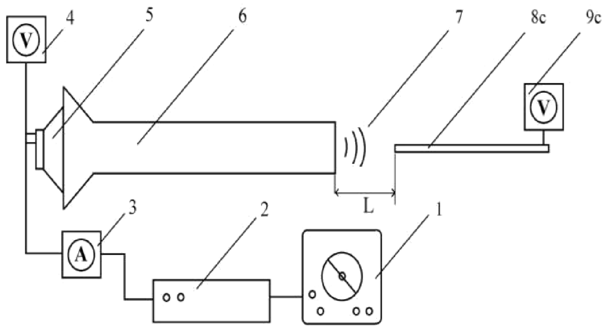

Fig. 3. Scheme of the experimental setup for the pressure measurement [4].

The principle of the used setup (Figs. 1–3) can be presented in a following way. A sine wave signal, produced by generator TESLA RC BM 365U (1), was transmitted through the amplifier Mosfet MDD. 2108M (2) to the loudspeaker SONY 1-825-378-11 (5) mounted on the one side of the cylindrical tube (6). In the case of liquid fuels, in the distance – L from the other side of cylindrical tube, the digital scale with combusted material was situated (9a). Combusted material was placed in a ceramic pot with the following dimensions: $5 \times 3.5 \times 1.1$ cm (8a). For natural gas supplied from city gas pipeline (9b) Teclu burner was used (8b). The gas flow was measured by the rotameter.

Measurements of the loudspeaker critical power required to extinguish the flame were made for each fuel. Speaker power was read by analog (3) and digital (4) meters. The whole procedure was repeated for different wave frequencies ranging between 30 and 50 Hz. The distance between the center of the flame and the end of the tube was always constant and was equal to 3 cm, with the flame located at the tube's axis.

In addition, for the critical values of the speaker power obtained for natural gas flame, the sound pressure was examined using KULITE XC-4-093-350M-BAR probe (8c). As in the previous case, results were read by the digital meter (9c).

The loss of mass, registered by the digital scale during the combustion of liquid materials, allowed to calculate the flame power. Also for gas burner, knowing the gas flow rate, it was possible to calculate the flame power.

3. Visualization

The phenomenon of the flame extinction for various fuels is presented in the Figs. 4 and 5.

a)

b)

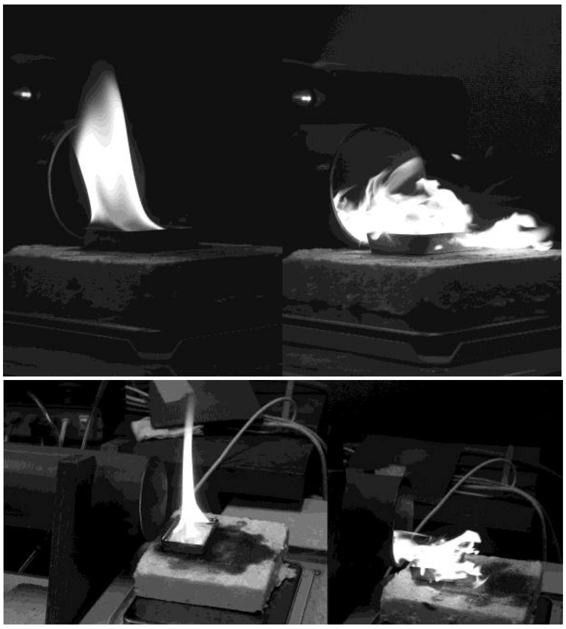

Fig. 4. Extinction of the diesel fuel flame (a) and gasoline flame (b).

When combusting liquid fuels (Fig. 4), the flame was in the shape of cone or pyramid – wide at the bottom and thin on the top. It looked solid, and was relatively stable. During the breakdown by the acoustic wave, the flame was expanding and sometimes was sucked into the tube.

Natural gas flame was characterised by the different shape. As can be seen from Fig. 5, it was taller and thinner. In comparison to the flames of liquid fuels, it was also much more prone to destabilization and extinction.

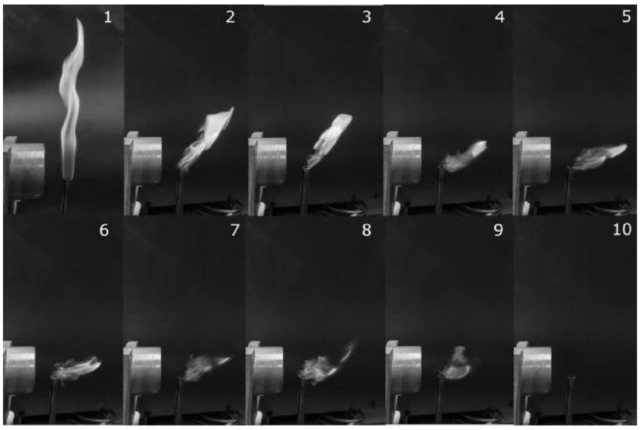

Fig. 5. Extinction of the natural gas flame.

4. The result of an experiment

4.1. Parameters of the acoustic wave suppressing the flame

Table 1 presents speaker parameters required for the total extinction of investigated flames. For each fuel the distance between the flame and the end of the tube was 3 cm.

As can be seen in the Table 1, the shape of flame and the type of flow (laminar or turbulent) are crucial for the flame extinction. Hence, laminar flames of liquid fuels were stronger and more difficult to disturb than turbulent flame of natural gas, even its power was much higher. Table 1 presents results for 40 Hz frequency, because only for this value extinction of all type of tested fuel took place. It is worth mentioning that diesel flame was also quenched at the frequency of 50 Hz, while the power supplied to the loudspeaker was 30 W, which is almost three times higher than for 40 Hz. However,

Table 1. Parameters of the speaker required to extinguish flames of various fuels.

Fuel	Frequency [Hz]	Speaker extinction power [W]	Flame power [W]	Comments
gasoline	40.00	51.66	1.2	wide and smooth, laminar, diffusion flame height: 0.20 ± 0.02 m diameter ranging between 0.001–0.04 m
diesel	40.00	11.21	0.6	laminar diffusion flame with split top height: 0.15 ± 0.02 m diameter ranging between 0.001–0.04 m
natural gas	40.00	5.93	7640	narrow, turbulent, diffusion flame height: 0.30 m diameter of 0.02 m

natural gas flame could be extinguished for a wider bandwidth, which allowed to make a number of other measurements which more adequately describe the acoustic waves affecting the flame.

The critical values of the sound pressure, quenching the gas flame, were measured with an acoustic probe. The measurement range was limited to the most effective frequencies, which is presented in Fig. 6.

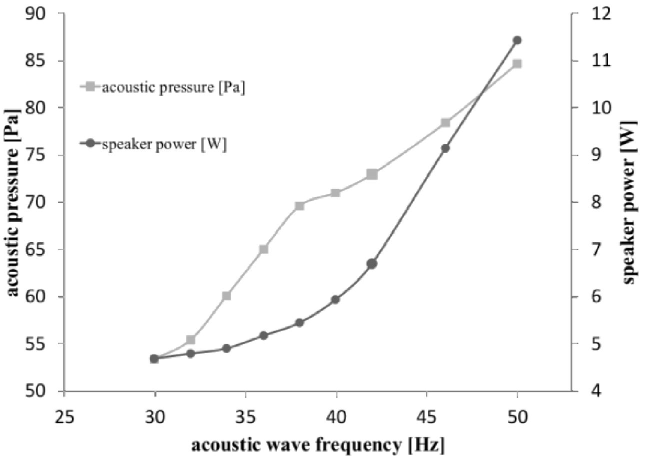

Fig. 6. Speaker extinction power and acoustic pressure as a function of acoustic wave frequency.

One may observe in Fig. 6 that with the increasing frequency the loudspeaker power needed to extinguish the flame increases exponentially.

A similar relationship takes place for acoustic pressure, except that in this case the increase is linear and more rapid in range of 30–40 Hz than at higher frequencies.

Summarising, the highest efficiency in the extinguishing of the flame (in relation to the power output of the loudspeaker to the power of the extinguished flame) is characterised by low frequencies, at the level of 30 Hz.

4.2. Laboratory stand limitation

Due to the limitations of some devices (30 W amplifier), the sound pressure of acoustic waves required to suppress liquid fuels could not be determined. To measure that pressure a long-lasting operation of the system was necessary, which significantly exceeded critical parameters of the amplifier. In turn, it could lead to an amplifier damage as well as it may result in speaker malfunction (in such a case the speaker was replaced).

Most of the attention was devoted to the frequency of 40 Hz. Although Fig. 6 shows that it is not the most effective value when it comes to flame extinguishing. Certainly, a frequency of 30 Hz would require lower powers to extinguish flame than those shown in Table 1. However, as it was mentioned before, such low values of the wave frequency were overloading the amplifier and speaker.

5. Summary

The construction of a fixed fire suppression/prevention system, based on acoustic waves, requires a number of parameters to be examined. Some of these parameters have been studied in the current article, and may be used to build such a device.

It is obvious that the extinction of a stronger wider fire than the one presented in this paper requires components generating waves with higher acoustic power. The crucial element of such a system is, of course, the loudspeaker which should be able to provide a high maximum power of at least – several hundred watts. Equally important is low bandwidth that allows to generate waves with frequencies of 30 Hz or even lower. Using the set of several smaller speakers could be also considered.

The most crucial aspect of the project is to keep the whole operation safe for the environment. One should remark that the acoustic pressure ought to be sufficiently high, otherwise instead of extinguishing the flame it may enhance the mixing of the fuel and the oxidizer and in turn strengthen a flame.

The last problem is the impact of acoustic waves on the human health. A high level of sound intensity – above 100 dB, can damage hearing. The frequency of the wave is also important in this context. It was found that infrasound, or sounds with frequencies lower than 20 Hz, have an adverse impact on human health. This spectrum of frequencies causes resonance vibrations of internal organs, and thus disrupts its functions leading to diseases, weaknesses, headaches or fainting. Taking the above limitations into consideration, it is very important to design such a system very carefully. It should save human health and life, not the opposite.

As it has been shown, the extinguishing of the fire by the acoustic waves is possible, not only in the micro-scale, but also in case of a real flame which could be a potential source of danger.

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