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INVESTIGATION OF THE USE OF THE ACOUSTIC EFFECT IN EXTINGUISHING FIRES OF OIL AND PETROLEUM PRODUCTS

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A b s t r a c t

This paper discusses the use of an acoustic effect and technique to extinguish flames when extinguishing fires of oil and petroleum products. The added value is also to analyze the development prospects to familiarize the reader with the current state of knowledge in the use of acoustic waves for extinguishing of oil and petroleum products. Some types and conditions of using the acoustic effect when extinguishing a fire are considered. Various options for using the acoustic effect in fire extinguishers are shown. The prospects and environmental friendliness of the acoustic method in extinguishing the fires of oil and petroleum products are noted.

Keywords:

Acoustic effect;
Oil;
Petroleum product;
Environment;
Firefighting;
Flame;
Acoustic fire extinguisher.

Introduction

The extraction of mineral resources, in particular, of natural hydrocarbons, today is one of the main types of anthropogenic activities that affect the environment [1, 2]. At the same time, the issue of cleaning the contaminated natural objects due to the ingress of liquid petroleum products into them is very acute [1б]. Mostly biological and chemical methods are used, both as a whole and separately [3, 4]. The scale of the extraction and processing of oil and petroleum products necessitates taking into account emergency situations, in particular, fires that can occur during various technological processes or during the storage of these hydrocarbons [5, 6]. Obviously, the most effective way to minimize the effects of the ignition of petroleum products is to prevent it. For this purpose, the situation is modeled [7, 8], the use of early response sensors [9, 10] and fire-extinguishing systems [11] are used. In cases where the fire occurs, various fire extinguishing means are used [12, 13]. In the countries of the Middle East, in the United States, Russia, Azerbaijan and other states, where one of the main types of economic activity is oil production, the issues of preventing both oil and petroleum products fires and preventing environmental pollution are especially relevant. Pure water is ineffective in extinguishing the fires of this class [14].

Currently, water is used to extinguish flames in addition to chemicals appropriately selected for the class of fire [15, 16]. So, mainly foaming agents of various compositions are used for liquidating the fires of oil and petroleum products, which also have a significant effect on water bodies and living organisms [17, 18]. The growing attention of the world community to the protection of the environment forces us to look for both new groups of chemical compounds [19, 20] and new approaches for extinguishing the fires of oil and petroleum products [21].

One of the interesting directions in this area is the use of the acoustic effect. A novel acoustic technology to extinguish flames is of great interest to people involved in fire protection.

The use of acoustic waves for flame extinguishing appears to be a novel future technology that is currently being tested and developed [22, 23]. The factors in favor of it are economic and environmental aspects (acoustic waves are not a chemical product). Furthermore, the use of environmentally safe technologies is associated with the possibility of a quick return to normal work after the flames have been extinguished. There are many more benefits to using this technique. In this regard, it is possible to indicate, among others, a wide range of operations (low-frequency waves have low loss because they are weakly attenuated by the medium in which

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they propagate) and energy benefits [24, 25]. This technique seems to be of interest to researchers, as shown by worldwide research and patents.

Research on the Use of Acoustic Waves to Extinguish Flames

Since many academic and research institutions around the world are conducting research into the use of acoustic waves for flame suppression, this indicates the hopes placed in this technology. The results of the conducted research are included in a few articles on the possibility of using acoustic waves for flame extinguishing.

It is worth noting that the driving force behind the search for innovative flame extinguishing techniques became an economic factor. This issue turned out to be so important that the US agency DARPA (Defense Advanced Research Projects Agency) has been interested in it since 2008 [26]. The aim was to find innovative and effective methods for extinguishing fires. The DARPA research used liquid fuel and loudspeakers placed on both sides of the tank. Due to the emission of acoustic waves, the flames were attenuated, dispersed, and finally extinguished. The IFS (Instant Fire Suppression) program was divided into two stages. In the first, the flame formation and propagation were analyzed. The results obtained led to the conclusion that interrupting the combustion reaction is a common way to extinguish flames. However, flames can also be viewed as a cold plasma that can be manipulated and controlled using acoustic waves to extinguish them [24, 27]. As a result of the analysis, the acoustic method has been identified as one of the promising ones. In practice, this technique appears to be safer to apply, cheaper to use (lower extinguishing costs), and environmentally friendly compared to commonly known flame extinguishing methods [22].

The research on the use of acoustic waves for flame extinguishing has also been carried out in Poland within the project No. 3 of the InIn+ programme entitled "Non-invasive project of acoustic extinguisher using natural mechanisms of sound wave propagation to extinguish liquid fires in closed spaces", co-financed by the Ministry of Science and Higher Education [28]. This research centered on the development and construction of a fire extinguishing device, hereafter referred to as a high-power acoustic extinguisher, which was then tested in an open space. The project work explained the principle of operation of the extinguisher, taking into account the disturbance of the combustion process in the flame boundary layer (molecular point of view) and the use of unmodulated and modulated acoustic waves to extinguish the flames. A tangible result of the research was the performance of the performance of analysis of the fire extinguisher performance and real-world tests, which fills the literature gap in this area [29, 30].

In practice, the effectiveness of a firefighting action using acoustic waves depends on the level of pressure turbulence, which must be sufficient to disrupt the flame front, stretch and weaken the flame, resulting in its extinguishment [31, 32, 33]. Friedman et al. examined determining how acoustic interference interacts with flames using a laminar diffusion line [34]. The elongation of the flame affects its aerodynamic distortion, which contributes to its extinction [35]. Deviation of one of the ambient parameters changes the direction of propagation of the flame front, which in turn increases heat emission until the flammability limit is exceeded [27, 31, 36]. In practice, depending on the electrical power supplied to the sound source, the sound pressure grows linearly only up to a certain point, which limits the use of the classical regression function model in its entirety [37].

Researchers noted that few publications have addressed the ability to extinguish flames fueled by gaseous fuels when, unlike liquids, no vaporization occurs [32]. Most often, liquid fuel is used for experimental purposes. Such a technique has been described in many Polish scientific publications. Their scientific novelty is also the presentation of the possibility of extinguishing flames with modulated waves, waves of different shapes, and frequencies in addition to the use of non-modulated waves (information on this subject can be found, among others, in the articles by Wilk-Jakubowski et al. [38] and Niegodajew et al. [32]. The research carried out in a broad context allows one to present the influence of various factors on fire extinguishing with the use of acoustic waves.

Niegodajew et al. showed that the lower the frequency, the easier it is to extinguish the flames, while the fuel charge has little effect on the extinguishing pressure [32]. Flame extinguishing is due to the cumulative effect of acoustic mean flow and oscillatory perturbations. The authors conducted their study in two steps. First, for a given frequency, flame power, and distance between the burner and the output of the device, they determined the minimum electrical power delivered to the speaker at which the extinguishing effect was observed. The higher the frequency, the more power had to be delivered to the speaker to observe the flame extinguishing. Each time the distance between the extinguisher output and the flame source or the power burner power increased, the required power that had to be delivered to the sound source to extinguish the flames increased. For this reason, it is recommended to use a sufficiently high-power loudspeaker whose lower bandwidth limit is well away from the operating frequency [32]. In a second step, the burner was removed, and sound pressure measurements (at the flame source location) were made for the determined speaker power. In practice, increasing the frequency and power of the flame had a noticeable and small impact, respectively, on the growing sound pressure at which the extinguishing effect was observed. Furthermore, the results obtained for different distances between the device output and the flame source are comparable with each other [32].

Niegodajew et al. through a single obstacle model also presented the influence of an acoustic screen in flame extinction [39]. During the study, the sound pressure level required to extinguish the flames was analyzed in two stages (fuel load, screen distance from device output, and the resulting sound field between the screen and the device output were taken into account). The largest range of variation in the sound pressure values was recorded for short distances from the screen. In practice, for small distances between the screen and the probe, a systematic increase in pressure is observed over the entire measurement range. For distances greater than 15 cm, little change in pressure was observed, indicating that the screen had little effect on the pressure level. In conclusion, the close environment affects the flame extinguishing process by acoustic waves. When the object is directly behind the flame, the extinguishing process will be hindered despite the increase in sound pressure level. Some results are illustrated showing the actual Schlieren image of the fuel flow in the absence of vibrations resulting from propagation of acoustic waves, as well as the image of the flow when the acoustic pressure increases [39]. In practice, the average effect of the flow does not depend on the excitation frequency (its value changes as the acoustic pressure increases) [40]. The flame will burst when a critical level of acoustic pressure is reached.

Węsierski et al. presented the relationship between acoustic wave parameters such as frequency, power delivered to the loudspeaker, and acoustic wave pressure and intensity [24]. On the basis of a series of experiments, the geometry of the wave beam outside the waveguide was determined. A wide beam angle is observed (the sound pressure decreases as it moves away from the device output plane). The research also resulted in the determination of the required power applied to the loudspeaker as a function of the distance from the device output, necessary to extinguish the flames, as well as in the relationship between the thermal power of the flame and the power applied to the loudspeaker (the determined ratio of the extinguishing power to the power of the flame has small variations and is equal on average to k_{AV} = 3.77 10-6 m^3) [24]. In summary, when low power is used to extinguish flames (up to 20-30 W), the operating range of acoustic technology is severely limited [27]. In practice, for acoustic waves to be effectively applied to extinguish flames, the assumed distance between the extinguisher output and the flame source should exceed 1 m, but it depends on the application. Since flames are difficult to extinguish using low-power sound sources, the authors note the need to use higher power. Thus, in the practical implementation of acoustic technology for flame extinguishing, it is possible to increase the distance between the flame source and the extinguisher output by using a high and very high power.

Experiments of Radomiak et al. are included for different distances from the device output [27]. An added value is the determination of the limiting sound pressure level (in the range 45÷55 Pa), below which no flame extinction phenomenon was observed. It can be noticed that the action of an acoustic wave of an appropriately selected frequency allows complete extinguishing of the flame, which was confirmed not only by experimental results, but also by visualization with a streak apparatus. The value of the flame extinction efficiency coefficient mostly grows with an increase in the frequency, while near the limit of the test interval, the function slightly changes its monotonicity. An increase in the flame extinction efficiency coefficient is observed when the distance of the flame source from the device output increases [27].

Stawczyk et al. presented an extinguisher that generates a directional acoustic flow capable of effectively extinguishing flames [41]. This experimental research was divided into two stages. In the first, the basic parameters of the acoustic extinguisher (impedance curve, sound pressure characteristics, and directional characteristics of the device) were determined, and in the second, the results showing the possibilities of extinguishing flames using acoustic waves were discussed. In this scope, an impact of acoustic wave parameters on the flame extinguishing efficiency, an influence of a distance between a flame source and a waveguide output (the results were limited to a distance of 1.2 m with 1000 W power delivered to the loudspeaker), an impact of frequency (from 14 to 21 Hz) on the flame extinguishing for a sine wave (an influence of acoustic wave frequency on a minimum power delivered to a speaker to extinguish the flames, and an impact of acoustic wave frequency on a minimum sound pressure at which the extinguishing effect was observed) were presented. For low frequencies, the increase in vibration amplitude was recorded, which translated into the extinction process. On the other hand, frequency mismatch may be associated with significant vibration of the speaker diaphragm, which is undesirable [41]. In the case of this extinguisher, good performance was observed at 14 Hz (then the power delivered to the extinguisher was the lowest). Physical limitations affect the design of the extinguisher. The use of higher-frequency waves allows the device to be smaller in size. However, it contributes to the increased power delivered to the sound source to extinguish the flames, which in turn is an undesirable factor.

In the works by Levterov, the possibilities of using the acoustic effect for identifying an emergency situation associated with the fire of petroleum products [42, 43], early detection of the fire [44], preventing [45] and extinguishing the fires [46] by using spectral signal processing are considered.

Acoustic techniques may be implemented for flame extinguishing in production halls, industrial facilities, or flammable liquid tanks oil and petroleum products. It can be a permanent or portable (mobile) element of objects or devices exposed to the presence of flames.

Thus, today the acoustic method is considered by a wide range of researchers for the possible use of fire detection and extinguishing.

It should also be noted that the use of the acoustic effect in extinguishing oil and petroleum products does not introduce additional polluting components into the environment, i.e. the technology is environmentally friendly. When extinguishing liquid oil products using the acoustic effect, there is also no contamination from the fire extinguishing agent. This is an obvious advantage of using acoustic technologies in extinguishing oil and petroleum product fires, as well as in their detection.

Below special cases of using the acoustic effect, namely, in fire extinguishers are considered.

Overview of the use of some acoustic fire extinguishers

The reported invention [47] allows fire to be extinguished in variable states of combustion, in phases of its development and composition. It uses a special ejector tube, whose task is to discharge the extinguishing streams at sonic velocities. The heat from the fire makes it possible to regulate the density of discharge and suction flows.

Acoustic fire extinguishers can have different designs. The small patent [48] presents an extinguisher that is capable of extinguishing flames with low-frequency acoustic waves in the range of 30 to 60 Hz. This is because, in practice, waves of such frequency are highly reliable and enable fast extinguishing of flames. As components of this fire extinguisher, there are: a sound wave generator, a power amplifier, a sound source, and a collimator, which includes a cylinder having a diameter that gradually decreases from the sound wave input to the sound wave output. These components are connected sequentially.

A device to extinguish flames by acoustic waves, which is equipped with a frequency generator, a dynamic loudspeaker, and a power amplifier, is an object of the invention [49]. It advantageously has a tube waveguide at one end, on which a sound source in the form of a dynamic loudspeaker is mounted, and at the other end an open end with an axially placed tube output. The same authors are also inventors of a method to extinguish flames with acoustic waves generated in a sound source through a frequency generator and a power amplifier [50]. This method is based on the fact that at the beginning of the waveguide, a sound source with an intensity of more than 0.5 W/m2 is activated. The operating frequency ranges from a few to a thousand Hz, after which the tip of the waveguide is directed towards the flames, which changes the shape of the flames. The consequence of this phenomenon is the gradual reduction of the flames and then their extinguishment.

In turn, the solution [51] discloses methods, systems, and devices to disrupt the phenomena inherent in flames. It turns out that flames can be controlled. Various combinations are allowed. An exemplary device may include a transducer that is configured to receive a signal and then output a longitudinal wave based on that signal. The component may be an acoustic wave amplifier that is coupled to the transducer. It is configured to direct the longitudinal wave to a form having less attenuation in the medium than the longitudinal wave at the output of the transducer. The solution can also include a chamber that has an input coupled to the transducer.

Devices for extinguishing flames with acoustic waves are also the subject of solutions [52-55]. The object of the invention [52] is a device to extinguish flames with acoustic waves, which is used in closed and open spaces. This device is an answer to improve the efficiency of flame extinguishing in case of incompatibility of phases of acoustic waves emitted at the output of the device by the front and back surfaces of the diaphragm of the sound source (the disadvantage of currently known solutions is the lack of use of materials suppressing the energy radiated by the back surface of the diaphragm, which, due to the phenomenon of destructive interference, translates into a decrease in the power of the emitted wave). Additional drawbacks include distortions in speaker processing and unfavorable vibrations on the walls of the enclosure. One solution to this problem, in addition to phase-shifting the radiation generated by the back surface of the speaker diaphragm to increase the power of the acoustic wave generated at the output of the device, is to minimize the effect of this radiation by using a material that is designed to absorb the radiation. The wave emitted in the suppression material is reflected by its inner surface, losing its energy due to friction, which is converted to heat. As a result, the waves emitted from the back surface of the woofer diaphragm are attenuated, thus reducing their effect on the waves emitted from the front surface of the woofer diaphragm.

Similarly, an object of the solution [53] is a device that can extinguish flames with acoustic waves, which can be used in closed and open spaces. The device, according to the invention, responds to the search for novel methods of extinguishing flames with acoustic waves, using for this purpose, in addition to acoustic power, waves emitted by the surfaces of loudspeaker diaphragms as sound sources. The device takes advantage of the movement of particles contained in the air, whose causative factor is the vibration of woofer diaphragms, due to the generation of appropriately modulated and amplified acoustic signals of a specified frequency and power. The propagation of the acoustic wave increases the speed of movement of air molecules at the edge of the flame, which translates into a reduction of the area where the combustion process takes place. As a result, the flames are suppressed until they are completely extinguished.

Similarly, the subject of the solution [54] is a device to extinguish flames with acoustic waves, designed to extinguish small fires in closed and open spaces. It has a housing in which an acoustic generator is installed together with a modulator, connected to an audio amplifier, which are battery- and mains-powered. Attached to the device housing is a chamber in the form of a tube with a cap installed to reduce its output. It serves as a waveguide and collimator for the acoustic waves generated from the sound source. The generated, modulated, and focused acoustic waves of low-frequency, high-, or very high-acoustic power can be used effectively to extinguish flames.

Thus, various trends and prospects for the potential application of acoustic technology are shown, including in fire extinguishers, for extinguishing fires of oil and petroleum products in open and closed spaces.

Conclusions

Thus, the acoustic technology for extinguishing the fire is promising for detecting the oil fires and extinguishing them. At the same time, it is obvious that the considered acoustic technology for fire extinguishing is environmentally friendly and does not introduce additional pollution into oil products and oil that burn. However, like any other approach, it has limitations. Therefore, there is a need for further research on acoustic techniques. This innovative technology continues to be developed and improved. However, to realize its full potential, further research is needed focused on defining the technology's range, its limiting extinguishing capabilities, testing for material strength, and the safety of its use by humans.

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Исследование использования акустического эффекта при тушении нефти и нефтепродуктов

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Реферат

В статье обсуждается использование акустического эффекта и метода для тушения пламени при тушении нефти и нефтепродуктов. Дополнительной ценностью является также анализ перспектив развития, чтобы ознакомить читателя с текущим состоянием знаний в области использования акустических волн для тушения нефти и нефтепродуктов. Рассмотрены некоторые виды и условия использования акустического эффекта при тушении пожара. Показаны различные варианты использования акустического эффекта в огнетушителях. Отмечены перспективность и экологичность акустического метода тушения пожаров нефти и нефтепродуктов.

Ключевые слова: акустический эффект; нефть; нефтепродукт; окружающая среда; пожаротушение; пламя; акустический огнетушитель.

Neft və neft məhsullarının söndürülməsində akustik effektdən istifadənin tədqiqi

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Xülasə

Məqalədə neft və neft məhsullarının söndürülməsi zamanı alovun söndürülməsi üçün akustik effekt və üsulun istifadəsi müzakirə olunur. Oxucunun neft və neft məhsullarının söndürülməsi üçün akustik dalğaların istifadəsi sahəsində mövcud bilik vəziyyəti ilə tanış olması üçün inkişaf perspektivlərinin təhlili də əlavə dəyərdir. Yanğının söndürülməsi zamanı akustik effektdən istifadənin bəzi növləri və şərtləri nəzərdən keçirilir. Yanğınsöndürmə cihazlarında akustik effektin istifadəsinin müxtəlif variantları göstərilir. Neft və neft məhsulları yanğınlarının söndürülməsi üçün akustik üsulun perspektivliliyi və ekoloji cəhətdən təmizliyi qeyd olunur.

Açar sözlər: akustik effekt; neft; neft məhsulu; ətraf mühit; yanğınsöndürmə; alov; akustik yanğınsöndürmə cihazı.