Study of Acoustic Waves for Fire Extinguishment: A Review

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Abstract-

The need for innovation and modernization in fire extinguishing techniques is extremely necessary. Accidents caused due to fire are disastrous and can lead to irreversible losses. With the rising amount of dangers to the environment in various aspects, it is essential to avoid as much damage as possible. The existing techniques have been created considering only their efficiency in extinguishing fires and not considering the harms they can cause to the environment. Another area of concern is the disasters caused by fire accidents in space. The use of traditional chemical extinguishers in space is necessary to be avoided as much as possible. Study shows that sound waves could be one of the potential alternatives for extinguishing fires. Research is necessary in the development of a similar practical method of fire extinguishing and analyzing which frequency of sound waves gives optimum results. A possible reason for the flame extinguishment due to sound waves can be that the continuously altering high and low pressure waves when coupled with high air flow velocity cause disruptions in the air-fuel ratio at the flame boundary which leads to diminishing of the boundary.

Keywords: *Fire Extinguishment, Sound Waves, Frequency, Environment Safety, Space*

Introduction-

Current extinguishers contain different kinds of chemicals depending upon their application. Generally, they are pressurized with Nitrogen or Carbon-dioxide (CO_2) and when this pressure released on the fire, it extinguishes the fire. There are many such asphyxiating and extinguishing agents like water, potassium bicarbonate, foam etc. All these agents have a common property of leaving by-products (for dry chemical-based fire extinguishers) behind it. The waste materials generated by these methods can be toxic and their harmful effects are something that were never given a thought to. Innovative methods are necessary to minimize the generation of this waste. To deal with fire, we need to have extensive information about fire and its working on the Earth and in space.

Fire-

Fire is basically a chemical reaction which has fluctuating degrees of heat and light. It can sustain itself until it is deprived of any of its source materials.Fires need a combustible, inflammable material source and a sufficient amount of oxidizing agentto start. When this mixture comes in contact with a source of heat, a chain reaction takes place due to rapid oxidation. Fire consists of four elements: fuel, oxygen and a heating element in a proper mixture and a chemical chain reaction. These four elements are collectively referred to as the Flame Tetrahedron.Fire can be extinguished when it isdeprived of any one of these elements. Asphyxiating agents deprive fire of oxygen, thus extinguishing it.

Application of Acoustic Waves-

Longitudinal waves are the waves in which displacement occurs in the same direction as, or in the opposite direction to, the direction of propagation of the wave. They produce compressions and rarefactions as they propagate through any medium. Acoustic (longitudinal) waves interact with each other. This interaction can be expressed in two different categories: constructive and destructive interference. When these waves are superimposed on each other, the total resultant amplitude gives the soundpressure or particle displacement at the point of interaction. The resultant phase of the wave cancels or amplifies points along the wave. Sound waves consist of a recurring pattern of high-pressure and low-pressure regions moving through a medium. The compressions are regions of high air pressure while the rarefactions are regions of low air pressure.

Effect of Sound Waves on Fire-

The idea of fire being affected by sound waves was discovered as early as in 1858 by the American scientist, John LeConte. In 1900, a German physicist, Heinrich Rubens demonstrated the effect of sound waves on fire through his experiment known as the Ruben’s Tube. It is necessary to understand first that acoustic or sound waves are basically longitudinal pressure waves. They tend to move in a back-and-forth (vibrating) motion so as to propagate. This motion can thus be utilized to drive away oxygen molecules from the fuel, thus extinguishing the flame. Secondly, as we know the Ideal Gas Law states that the change in pressure is directly proportional to the change in temperature ($PV = nRT$), when the pressure waves are directed at the source of the fire,they will decrease the pressure at the source and in turn decrease the temperature of the fire. Promising research and studies in this field were first carried out by DARPA (Defense Advanced Research Projects Agency) in USA. They concluded from their research that "a threshold acoustic velocity must be applied to the flame in order to achieve extinction, rather than a specific frequency or acoustic pressure." However, it has been identified that this is not always the case. Frequencies between 0Hz to 10Hz do not prove to be effective in extinguishing flames, but frequencies between 30Hz to 60Hz show promising signs in the same. Combustion is a chemical process in which the substance rapidly reacts with oxygen and gives out energy in the form of heat and light. Acoustic fields have a significant effect on this process of combustion. When acoustic oscillations are combined with the vibrations of heat released from the fire, it alters the transportation process of combustion.

The light emitted by fire exhibits dual nature.Light can act as a wave as well as a particle. This wave-particle duality of light is the focus of our consideration. The pressure waves emitted in the form of sound affect the air particles by pushing and pulling them away from the source of the flame. Also, at the proper frequencies, the acoustic waves produced by the wave extinguisher are going through a process of destructive interference to interrupt the natural behaviour of the flame.

Fire in Space-

In outer space, fire reacts differently to that on the Earth. The fire formed in space has different shapes and properties due to presence of zero gravity. In space, fire flames are in the form of semi-circles with a blue colour flame. Fire spreads from one air molecule to the other. These air molecules act as heat propagation elements. This process of convection is done by ventilation fans in the space station. In space, the smoke caused by these fires is not directed towards smoke detectors and thus there is less chance of detection of fire at space stations. Being able to extinguish fires in space without the use of water or any other chemicals is a real boon, but on the other hand generating sound waves would require electricity and astronauts would need to see the flames to aim the sound waves at the exact point of source.

Ultrasound-

It has been seen that ultrasonic frequencies have an effect on the chemical kinetics of any chemical reaction. This high frequency (above 20000 Hz) is seen to cause excitation which will prove to aid combustion. It might also delay and perturb the chemical reaction which depends on the bonding for the chemical compound for the frequency under consideration. Actual effects of ultrasound for extinguishing flames have not been studied yet as optimum results were obtained for a frequency range of 60 Hz.

Experimental Procedure-

1) A tone generator is used for producing sound frequencies. Tone generator or a signal generator is a device which converts electronic signals into sound frequencies. Source of the electronic signal is a DC current modified using integrated circuits. This signal passes through a coil located near a permanent magnet and connected to a flexible membrane. The signal causes rapid fluctuations in the surrounding magnetic field causing attraction or repulsion from the fixed magnet, thus inducing vibrations in the membrane to generate sound.
2) The sound waves are further directed towards a subwoofer. The subwoofer is essentially a system designed to play the lowest bass frequencies. It also has a built-in (active subwoofer) or an external (passive subwoofer) amplifier. The subwoofer particularly amplifies the low frequency signals (30 Hz to 40 Hz) which are necessary for this experiment.
3) The low frequency sound waves are further directed towards the vortex tube. A vortex tube is basically a cylindrical object which has a stretchable membrane on one side and is open on the other side. When sound waves are focused on this membrane, the membrane snaps forward and collidesdirectly with the air molecules. This accelerates the air molecules towards the other open end and sets off a continuous series of high-speed collisions of air molecules. This rapid movement forms a stream or jet of air which is directed towards the fire. When the jet of air escapes the opening of the vortex tube into the still air outside, it forms a 'stable donut-shaped gaseous projectile'. This is called a toroidal vortex or vortex ring, hence the name vortex tube. The toroidal vortex is caused by the friction of the jet of air with the edges of the tube's opening and the slow-moving air outside the tube.
4) The stream of air escaping from the vortex tube thus proves useful in extinguishing fires as explained in the previous sections.

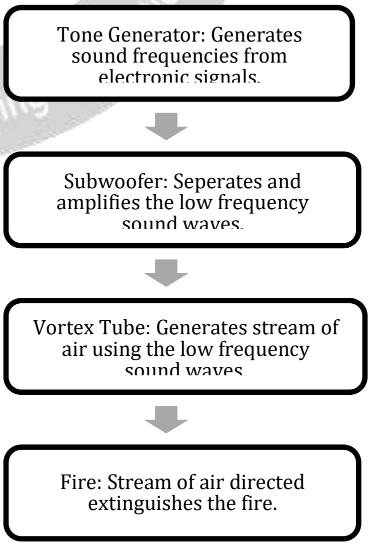

Fig.1 illustrates the experimental procedure using a block diagram as shown-

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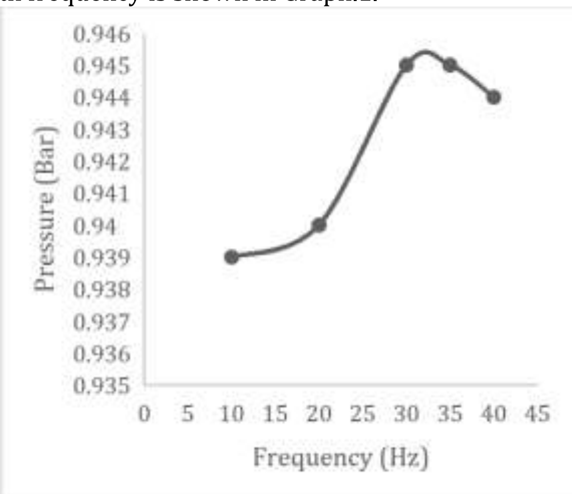
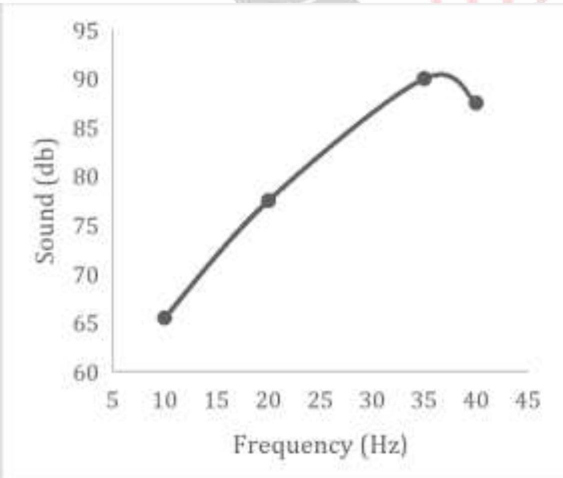
Experimental Results-

Sound waves significantly affect the fire extinguishing process. To evaluate the results, fire was exposed to various sound frequencies: 0Hz, 10Hz, 30Hz, 35Hz and 40 Hz. Variation of pressure, sound and acoustic velocity were evaluated with respect to the above chosen frequencies. Sound travels in the form of waves, which are simply variations of pressure in a medium. The energy from vibrating objects, such as speaker membranes, moves from particle to particle in the air in a repeating pattern of high and low pressure zones that is perceived as sound. It is found that the effective range was between 30 Hz and 40 Hz, within the range of human hearing. The effect of variation of pressure with frequency is shown in Graph.1.



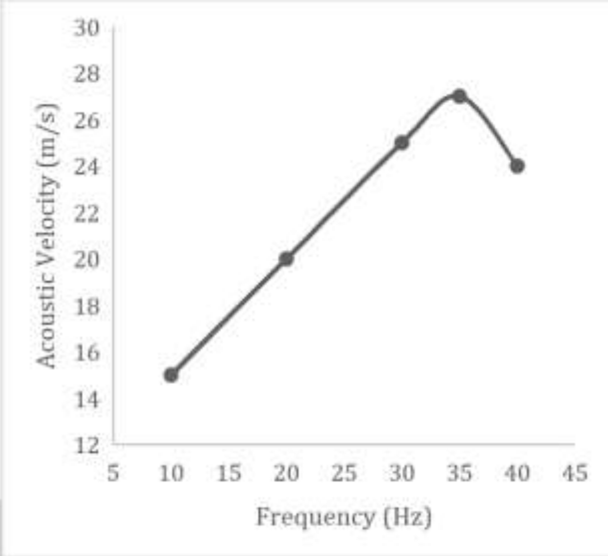
Graph.1 Variation of Pressure with Frequency

The effect of variation of decibels of sound with the frequency is shown in Graph.2.



Graph.2 Variation of Sound with Frequency

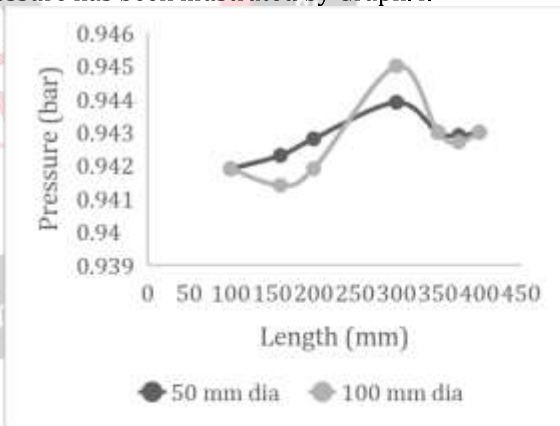
The effect of variation of acoustic velocity with the frequency is shown in Graph.3.



Graph.3 Variation of Acoustic Velocity with Frequency

The research has also revealed the effects of important parameters such as the length to diameter ratio of the vortex tube on the acoustic velocity and pressure of waves which has also been used in this experiment.Experimentally, the geometry of the vortex tube was optimized considering important parameters. The chosen variations were 100 to 400 mm for length and 50 to 100 mm for diameter. It was found that the length of 300 mm and diameter of 100 mm show the optimum pressure, velocity and sound for extinguishing fires.

The effect of geometry of the vortex tube on the pressure has been illustrated by Graph.4.



Graph.4 Effect of Vortex Geometry on Pressure

The effect of geometry of the vortex tube on the acoustic velocity has been illustrated by Graph.5.

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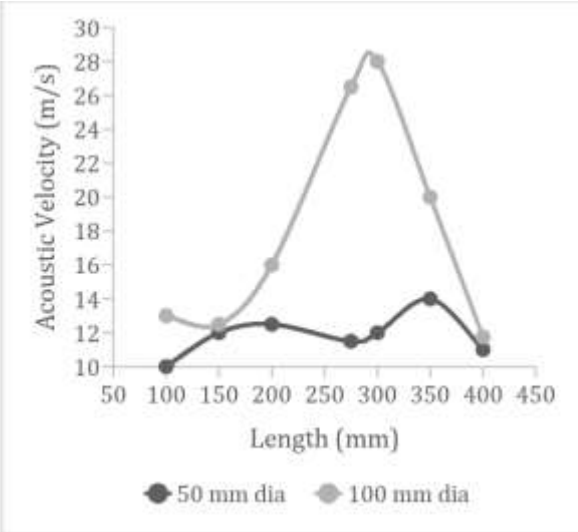
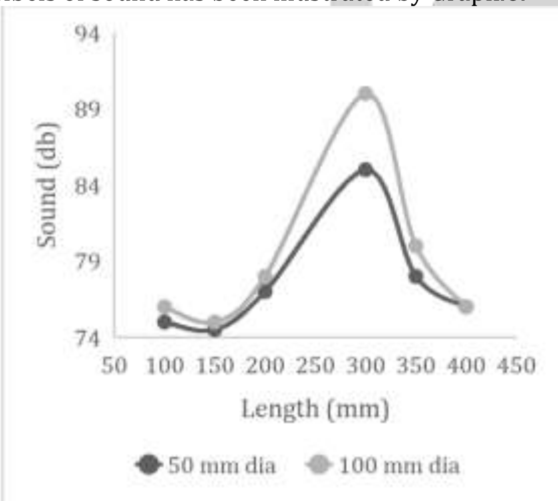


Graph.5 Effect of Vortex Geometry on Acoustic Velocity

The effect of geometry of the vortex tube on the decibels of sound has been illustrated by Graph.6.



Graph.5 Effect of Vortex Geometry on Sound

Suggested Applications-

A few practical applications of fire extinguishing using sound waves have been suggested as follows. Further research is essential for their implementation:

5) Sound waves can be used for extinguishing fires with the help of drones. Sources of sound generation can be attached to the drones which can thus cover a large area in a small period of time and can also maintain their distance from fires for safety. This avoids the actual contact between humans and fires.
6) Installation of permanent automatic systems of fire detection and extinguishing using sound waves can result into quick response to fires and avoid their spread.
7) Traditional extinguishing agents like Nitrogen gas Carbon-dioxide gas (CO_2) can be coupled with the sound waves to increase the efficiency of fire extinguishing.
8) In space, the use of sound waves for extinguishing fires can prove to be very efficient. Avoiding the use of traditional fire extinguishers reduces the chance of addition of more space debris as sound waves will produce no waste by-products.
9) Sound waves can play a very important role in extinguishing fires in areas which are difficult for humans to approach. Sound waves can be aimed at the source of fire from a long distance and thus the spread can be avoided.

Conclusions-

From the above experimentation and research, we have thus reached the following conclusions:

1) Sound waves between the range of frequencies 30 Hz to 40 Hz have shown to have effect on flames and thus possess the ability to extinguish fires.
2) The vortex tube necessary to be included in the construction of this experiment has the following dimensions for optimization of extinguishing effect: Length is 300 mm and diameter is 100 mm.
3) Use of sound waves for extinguishing fires is an environment-friendly process as it doesn't include the use of chemicals which are traditionally used in fire extinguishers across the world. It also helps conserve the resources like water for their use in other applications.
4) This application of sound waves could prove to be a massive breakthrough and could make extinguishing fires very much safer for humans.

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