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Improvement of firefighting techniques by using sound waves

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ABSTRACT

Fire is a particularly feared hazard. Therefore, a fire extinguisher is very important equipment. Unfortunately, existing fire extinguisher has some drawbacks such as using a chemical compound which is dangerous and it leaves a residue. Therefore, the need for a new fire extinguisher method is needed to overcome this problem. After various researches, it was found that sound waves can be used as an alternative method to extinguish flames. Acoustic pressure and air velocity produced from a speaker is the fundamental concept used to explain how sound waves put off flames. In this paper, we proposed a new method using the sound wave to extinguisher fire. Our method was using a speaker and a converging tube to focus the sound wave to overcome the fire energy and thus put the fire down. The aim is to develop a portable fire extinguisher to study and analyzes the effect of different frequency of a sound wave on flames. Experiments are conducted to find a suitable frequency range to extinguish the flame and to analyze the acoustic-flame interaction. Three different sources of flames were used with three different states of fuel (solid, liquid and gas). Using this method, a different set of experiments were conducted to find the range of frequencies within which fire can be extinguished and found that fire can be extinguished between 48 Hz to 60 Hz. Also, we found the optimum frequency as 53Hz. From the result of the experiment, the sound waves manage to extinguish all flames of different fuel types. We also found the applications of this extinguisher at Travancore Titanium Products (TTP) Ltd., Kerala, India. However, in both experiments the flame boundary used was relatively small as compared real fire accidents due to safety consideration. Nevertheless, this sound wave based fire suppression technology could be used to combat early stages of fire accidents.

Keywords— *Fire, Chemical extinguisher, Sound fire extinguisher, Fire extinguishing effect, Sound, Putting off Fire*

1. INTRODUCTION

Existing fire extinguishers contain different chemicals, depending upon their application. Generally, they are pressurized with Nitrogen or Carbon Dioxide (CO_2), when this pressure released on fire will extinguish the fire, as we know there are many such firefighting agents such as water, potassium bicarbonate, evaporating fluorocarbons etc. All these agents have the same property of leaving an unproductive system behind it. To deal with Fire we need to have complete information on fire and its working. The formation of fire requires three elements in a proper mixture they are fuel, oxygen and heating element. There is a chance of extinguishing the fire by sound. If we remove the heating element or move it apart from fuel fire can be extinguished.

This particular task is done by sound. In-depth research on sound could help. A mechanical wave of pressure and displacement, through a medium such as gases, liquids and solids. As we underlined above sound is pressure wave and displacement caused in the medium through with particles will move in a random direction, and transferring the pressure from one particle to the other, hence this how sound travel in any medium. Sound can be travel in two forms they are:

1.1 Longitudinal waves

Longitudinal waves are waves in which the displacement of the medium is in the same direction as, or the opposite direction to, the direction of travel of the wave. Mechanical longitudinal waves are also called compression waves because they produce compression and rarefaction when traveling through a medium.

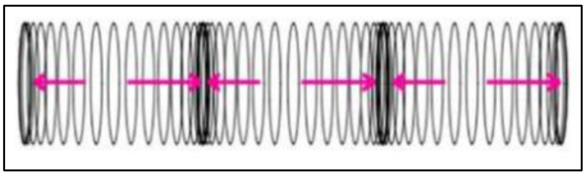

Fig. 1: Particle movement in longitudinal waves

1.2 Transverse Wave

A transverse wave is a moving wave that consists of oscillations occurring perpendicular (or right angled) to the direction of energy transfer. If a transverse wave is moving in the positive *x*-direction, its oscillations are in up and down directions that lie in the *y*–*z* plane. Light is an example of a transverse wave. With regard to transverse waves in matter, the displacement of the medium is perpendicular to the direction of propagation of the wave. A ripple in a pond and a wave on a string are easily visualized as transverse waves [9] [11].

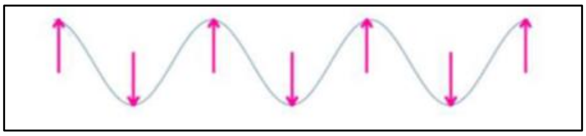

Fig. 2: Particle movement in transverse waves

2. FIRE

To understand how best to extinguish a fire, there must first be an appreciation of the three elements that make up the 'fire triangle': heat, fuel and oxygen. As fire is primarily a chemical reaction, removing one or more of these three factors will prevent the combustion from taking place [11].

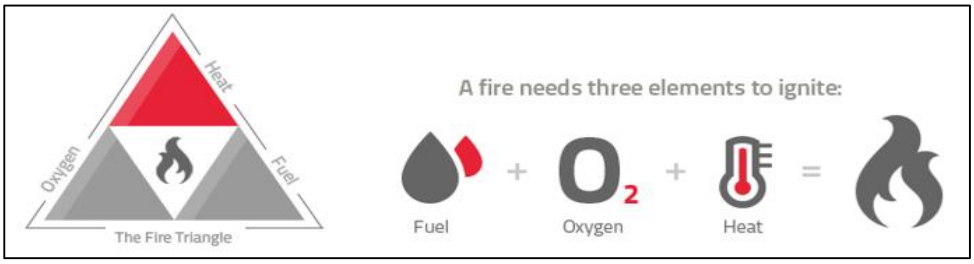

Fig. 3: Fire triangle and elements of fire

3. FIRE EXTINGUISHING METHODS

If the three parts of the 'fire triangle' are kept in mind, extinguishing a small blaze should be a matter of common sense. The principles of fire extinction state that a fire will be put out if one of the three elements are removed, and this can be done using three different approaches. They are Cooling (Cooling the Burning Material), Starving (Removing Fuel from the Fire), Smothering (Excluding Oxygen from the Fire).

Table 1: List of class, method and suitable extinguishers for fire

Class	Source	Method	Sutable Extingushers
A	Paper Wood	Cooling Blanketing	Water type (CO_2 cartridge type) Water (stored pressure type) Water bucket Sand bucket
B	Petrol Kerosene Diesel	Starvation Smothering	BCF CO_2 Dry chemical power Sand bucket
C	LPG CNG	Smothering Starvation	BCF CO_2
D	Sodium Phosphorus	Smothering	Special type DCP
E	Motors Transformer	Smothering Starvation	CO_2 DCP
F/K	Oil	Blanketing	AFFF fire extinguisher

4. PROBLEM STATEMENT

The current method of firefighting has many drawbacks such as toxic to humans and leaves residue (for dry chemical base fire extinguisher) while water base fire extinguishing techniques freezes in cold climates and conduct electricity. Using sound wave with a certain frequency as a fire extinguisher will have advantages as they are not leaving any residues and toxic material behind.

5. OBJECTIVES

(a) To check the frequency range used to extinguish flame found by previous researches.
(b) To identify an optimal range of frequencies

(c) To identify classes of fire that can be extinguished using sound waves.
(d) To identify locations where new firefighting techniques are required in TTP.

6. WORKING PRINCIPLE

This concept utilized the scientific principle of physics and the engineering aspects of electronics to successfully suppress a flame. Based on the physical aspects of acoustic waves, it is important to understand that acoustic wave patterns are referred to as longitudinal pressure waves –meaning that the waves move in a back and forth vibrating motion in which they are able to agitate air molecules away from the fuel of the flame. Secondly, we hypothesized that the physical aspect of *The Ideal Gas Law* has an effect on suppressing a flame. *The Ideal Gas Law* states that Pressure Times Volume is equal to the constants *n*, the substance of gas and *R*, the universal gas constant multiplied by temperature (PV=nRT). Therefore, when the pressure waves are being directed at the source of a flame, it will decrease the pressure at the source, which in turn will decrease the temperature of the flame [9].

7. DESIGN

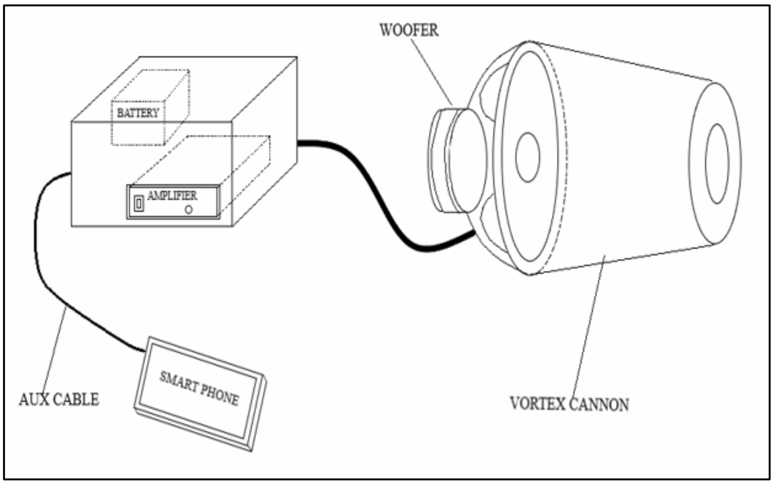

Fig. 4: Basic design of the device

8. EQUIPMENT'S REQUIRED

8.1 Hardware

100 Watt Speakers
500 Watt Amplifier
Vortex tube (converging)
12 V Battery

8.2 Software

Frequency Generator Application

8.3 Wiring diagram

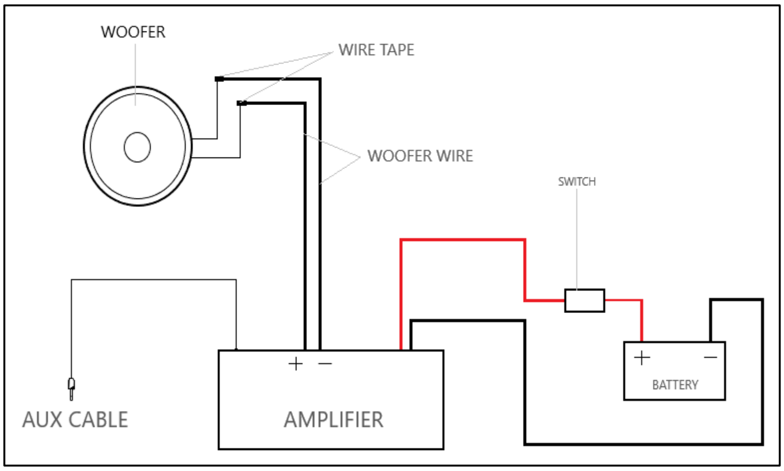

Fig. 5: Wiring diagram of a device

9. EXPERIMENTS AND RESULTS

9.1 Optimization of frequency

From the results of previous experiments done by previous researchers from DARPA. It was stated that the optimum sound frequency for fire extinction is 60 Hz. Eryn Beisner's acoustic flame suppression microgravity environment was stated that the optimum sound frequency for fire extinction is 30.6 Hz. According to a sound lens for a sound fire extinguisher, the sound fire extinguisher needs to produce low frequency sound less than 100 Hz. This experiment will be focusing on the observation in the frequency range of 30– 100 Hz in order to confirm the results from previous researches [1] [4] [7] [10]. So the first stage of the experiment is conducted to confirm the frequency found in previous researches. A candle flame was first tested to initiate the experiment. The sound wave was able to extinguish the candle between 48 Hz and 60Hz.

The second stage of the experiment is conducted to find optimum frequency from the above frequencies (between 48 Hz and 60Hz) found in the first stage. A candle flame was used in the experiment. An optimum distance, 30cm, is assumed by trial and error method and the candle flame is extinguished by using all the above frequencies and the time needed to extinguish the fire. A graph is plotted by using this data, which is shown in figure 6.

Table 2: Frequency-time table for three experiments

Frequency (Hz)		48	49	50	51	52
Time Taken (Sec.)	Expt. 1	1.873973	1.634783	1.100341	0.956895	0.803614
	Expt. 2	1.968774	1.220414	1.125721	0.938701	0.892493
	Expt. 3	1.734569	1.567894	1.394567	1.189546	0.938597
	Avg.	1.859105	1.474363	1.206876	1.028380	0.878234
Frequency (Hz)		53	54	55	56	57
Time Taken (Sec.)	Expt. 1	0.692591	0.756975	0.861255	0.963842	1.195678
	Expt. 2	0.738588	0.823924	0.864036	0.938701	1.192396
	Expt. 3	0.893752	0.997587	1.012395	1.093182	1.182321
	Avg.	0.774977	0.859495	0.912562	0.998575	1.190131
Frequency (Hz)		58	59	60		
Time Taken (Sec.)	Expt. 1	1.253793	1.298798	1.303614		
	Expt. 2	1.210357	1.287314	1.293829		
	Expt. 3	1.204059	1.289125	1.310456		
	Avg.	1.222736	1.291745	1.302633		

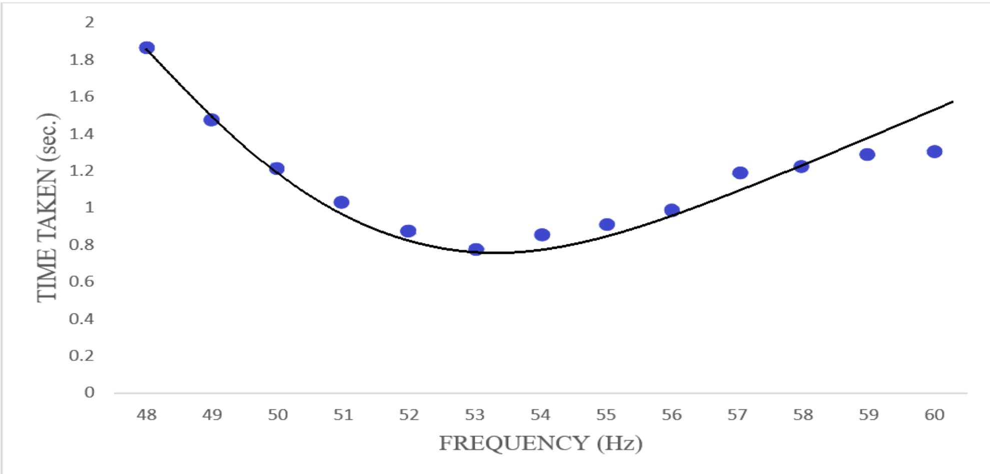

Fig. 6: Variation of time with frequency

The sound wave was able to extinguish the candle at 53 Hz within 0.774977sec. The figure-7 shows the sequence of high speed images of candle flame leading to flame extinction. It can be seen that the flame boundary resonates (back and forth) with the sound wave. After a certain period of time, the flame boundary slowly thins due to varying high and low pressure, which induces air velocity and causes toward flame extinction.

Fig. 7: Sequence images of candle flame extinguishing

9.2 The effect of distance on the extinguishing of the fire

Now, 53Hz is used to test the change of time taken to extinguish the fire with the distance between the vortex tube and flame. Its graph is shown in figure 8.

Table 3: Effect of time taken on distance

Distance (cm)	10	20	30	40	50
Time Taken (sec.)	0.424912	0.556813	0.723569	0.783265	0.893569
Distance (cm)	60	70	80	90	100
Time Taken (sec.)	0.938645	1.038241	1.278459	1.438714	1.578108

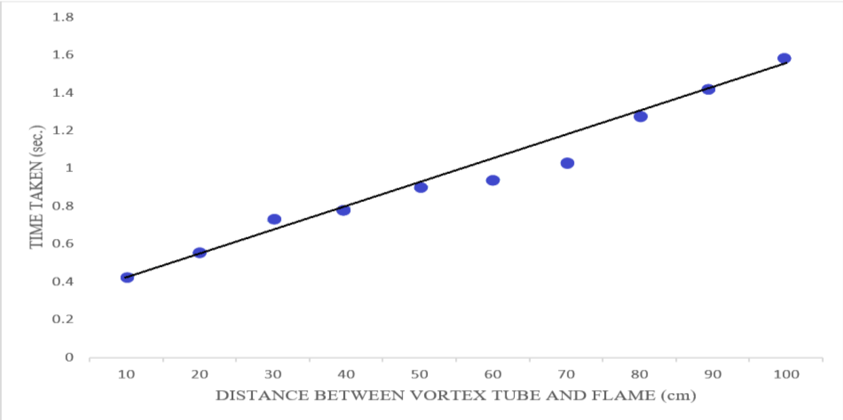

Fig. 8: Effect of time taken on the distance between the vortex tube and flame

From the graph, it shows that the shape of the curve is linear. So the distance between the vortex tube and flame increases the time taken to extinguish fire also increases. The third stage of the experiment is conducted to find out the interaction of sound with different classes of fire caused by different fuels in different states. There are three types of flame that are going to be tested, solid, gas, and liquid fuels, of which each is a single representative for each thermodynamic state of a material. The fuels are wood, LPG and kerosene.

9.3 Interaction of sound with classes of fire

9.3.1 Gas fuel based fire: In gas based fuel flames, the flame extinguishes instantly within 3 seconds. Figure-9 shows a sequence of images of gas fuel based fire leading to extinction.

Fig. 9: Sequence of images of gas fire leading to extinction

9.3.2 Solid fuel based fire: For solid fuel (wood) based fire, the flame doesn’t extinguish rather it burns quickly, however, the flame boundary diminishes gradually over time (approximately one minute). Figure-10 below shows a sequence of images of solid fuel based fire leading to extinction.

Fig. 10: Solid based fuel flame extinguishing

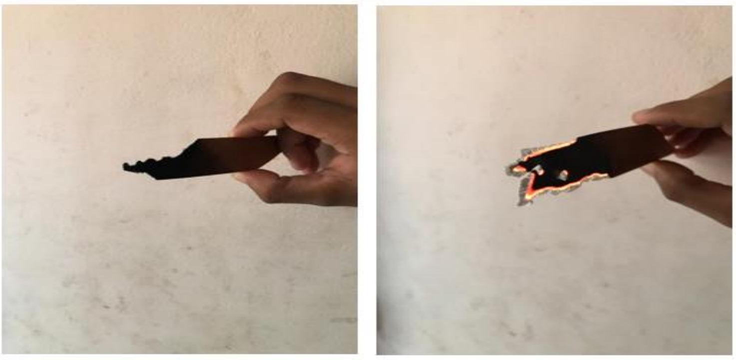

Fig. 11: Penetration of fire in the wood

9.3.3 Liquid fuel-based fire: In liquid-based fuels (kerosene) the flame is extinguished at about five seconds. Figure-12 below shows a sequence of images of liquid fuel based fire leading to extinction.

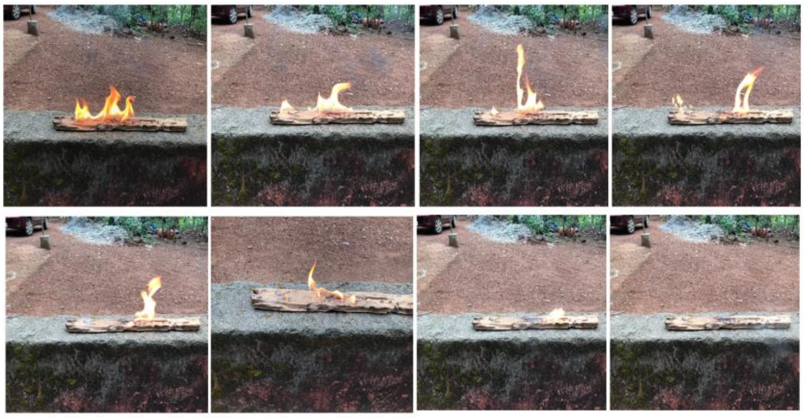

Fig. 12: Sound wave interaction with liquid-based fuel

Table 4 below shows a summary of results obtained after acoustic excitation was performed on three different fuel sources.

Table 4: Summary of results

Fuel type	Frequency	Times took
LPG	53Hz	3 seconds
Kerosene	53 Hz	4.5 seconds
Wood	53 Hz	1 minute (quickly burned)

From the above experiments, sound waves can be used to extinguish fires whose fuel sources are solid, liquid, and gas. In the experiment, we used LPG, kerosene and wood. This shows that this device can be used to extinguish the following classes of fire.

Table 5: Classes and types of fire

Class of fire	Types of fire
Class B	Fires are fires in flammable liquids such as gasoline, petroleum oil, and paint. Also included are flammable gases such as propane and butane. Class B fires do not include fires involving cooking oils and grease.
Class C	Fires are fires involving burning gases like natural gas.

The fourth stage is to identify the locations where alternative firefighting methods are needed. The locations are shown below.

Table 6: Proposed replacements at TTP

S no.	Location	Class of fire	Type & numbers	Proposed replacement
1	Furnace oil storage & pumping station	B	DCP-4, Mechanical Foam-4, CO_2 -1	DCP-3, Mechanical Foam-3, CO_2 -1, Sound extinguisher-2
2	Generator house & oil storage	B, E	DCP-6, CO_2 -2,MechanicaL Foam-1	DCP-5 ,Mechanical Foam-1, Sound extinguisher-3
3	SAP maintenance	B	DCP-1	DCP-1, Sound extinguisher-3

10. COST ANALYSIS

10.1 Cost of conventional fire extinguishers

A home single-use fire extinguisher that is capable of fighting A, B or C type fires costs RS.2000-RS.4000 [5]. Multi-use home and office fire extinguishers typically cost RS.2800- RS.5600. Some fire extinguishers are designed for specific areas such as the kitchen or in the car. Typically, fire extinguishers for the kitchen or car are single-use and cost RS.1050- RS.2000 [5]. Industrial fire extinguishers, which often are capable of putting out A, B, C and D type fires, cost RS.21000- RS.60000. The tanks of these fire extinguishers are often colored yellow, rather than the traditional red, to indicate the ability to put out D-type fires [5]. Refilling or recharging a fire extinguisher can usually be done by a local fire station. If they don't provide the service, they will know who does. Refilling a fire extinguisher typically costs RS.1400-RS.1750 [5]. Wall mounts for fire extinguishers cost RS.500- RS.7000 [5]. Fire extinguisher signs cost about RS.210- RS.1050 [5].

10.2 Cost of sound fire extinguishers

Table 7: Cost of components of fire extinguisher

S no.	Item	Cost
1	500-watt Amplifier	RS. 1600
2	100-watt Woofer	RS. 850
3	Vortex cannon (Plastic Container)	RS. 150
4	12 V Battery	RS. 850
5	AUX cable	RS. 50
6	Aluminum Foil	RS. 248
7	Insulation Tape	RS. 12
8	Miscellaneous	RS. 50
	Total	RS. 3810

The fire extinguisher that we have made, cost around RS.3810. Although there are certain fire extinguishers available for the same and below this price range, fire extinguisher using sound waves is capable of extinguishing fire of classes B and C. Thus by considering these factors, the above-mentioned fire extinguisher is capable of extinguishing different types of fires, also provides a better class of performance while considering other conventional extinguishers of same price categories and so is worth the money.

11. ADVANTAGES AND DISADVANTAGES

11.1 Advantages

(a) There is no residue compared to chemical fire Extinguisher.
(b) Nontoxic to the environment as well as human.
(c) It is light in weight.
(d) There is no expiration date.
(e) There is no refilling date.
(f) It can replace chemical as well as a water fire extinguisher.

11.2 Disadvantages

(a) Electricity is needed for operation.
(b) Electronic components are needed.
(c) A class and D class fires are difficult to extinguish.

12. CONCLUSION

The idea of extinguishing the fire with sound can be an innovative one, however, it is efficient and effective, and can be used in today’s world. Based on the experiment result obtained it can be seen that the sound wave can extinguish flames. The frequency range at which the flame can be suppressed is 53 Hz. However, in these experiments, the flame boundary created was relativity small as compared size or sound intensity of the speaker and does represent a real fire-related accident. This is mainly due to the concern of safety issues as a larger flame could lead to uncontrollable accidents. Nevertheless, this sound wave based fire extinguishing could be used to extinguish initial stage fires. With many possible applications, fighting fire with sound is a promising venue.

In order to extinguish large area flames acoustically using the current setup, either a larger or more powerful speaker would need to be used. Directly increasing the output power of a speaker, will cause signal distortion of the output signal. One can multiplex speakers to achieve extinction of larger flames, however, the practically of such a system comes into question. Hence there is a need for further research investigation to attempt for large fire extinguishers.

In the experimental part, different parameters could be used to further explore is study such as using different intensity of sound (by using different speaker power rating), positioning of sound towards the fire source and size of flame (or flame intensity) & varying design of vortex tube. Apart from that, measuring the time taken to extinguish the fire, exit air velocity and temperature could also be taken into account. A smoke generator could also be used by pumping smokes into the vortex tube to study how the fluid propagates out from vortex tube.

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