International Archives of Medical Research 16:2 (2024) 24-33

ORIGINAL RESEARCH

The Effect of Various Molotov Cocktails on Different Surfaces and Evaluation of Fire Changes

Received Date: 19.02.2024, Accepted Date: 18.07.2024 **DOI: 10.56484/iamr.1439171**

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Abstract

Objective: *Molotov cocktails are a classic homemade weapon used over the past 80 years; also known as gasoline bombs. However, there is not enough research in the literature. Molotov cocktail is classified as a mildly explosive substance. But a Molotov cocktail is not an explosive. This is a handmade lighter. It is used to set fire to targets in terrorist attacks.*

Method: *In our study, classic homemade Molotov cocktails were used. Oil, diluent, sugar, cologne, epoxy resin, paraffin, egg white, liquid and solid detergent, bleach, wood glue were added to the mixture. Parameters such as burning temperature, burning time, glass and nail spreading diameter, and residues of the Molotov cocktail were investigated. The prepared molotov cocktails were broken on 5 different floors, and the effect of changing the floor on the parameters was investigated..*

Results: *In our study, 51 (59.3%) of 86 molotov cocktails were broken. Most of the destruction occurred in the wall. According to the results we obtained, a relationship was found between the content of the Molotov cocktail, the burning temperature and the time. It was found that the damage was increased with the addition of substances to the mixture.*

Conclusion: *In addition, in our study, it was noticed that the Molotov cocktail did not explode by itself and did not cause damage to the environment by throwing nails.*

Keywords*: Molotov Cocktail, Terrorism, Explosives, Incendiaries.*

Introduction

The purpose of the Molotov cocktail is to set the targets on fire[1]. Molotov cocktails, also called incendiary bombs, were primarily used in wars to destroy tanks. Now it is used by terrorists and protesters to harm the environment[2]. Injuries or deaths occur as a result of the Molotov cocktail fire. In our country, in 2009, 17 years old Serap Eser died due to a Molotov cocktail thrown on a bus[3]. A reference study is required for a correct approach.

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Molotov cocktails are of 2 types; classical molotov cocktails and chemical molotov cocktails. In classical molotov cocktails, the preferred combustible material is placed in a glass bottle. Cotton or wool fabrics are generally preferred as wicks because synthetic fabrics containing nylon can melt quickly and prevent fire. The piece of fabric is inserted from the head of the bottle so that a part of it remains outside the bottle. The outside part of the fabric is burned with lighters, matches and similar igniters and thrown to the target surface, breaking the glass. In addition, by creating a mixture of substances such as sugar, liquid detergent, polystyrene foam, motor oil and rubber cement, it is ensured that it adheres better to the target surface and is difficult to extinguish [4].

Some publications describe chemical molotov cocktails that cause fires as a result of chemical combinations. These molotov cocktails are not favored by protesters because the chemicals are poorly known and difficult to obtain. In these molotov cocktails, instead of using fabric for ignition, the reaction of substances is used. For example, a mixture of sulfuric acid and gasoline is placed in a glass bottle and the bottle cap is closed. The mixture of potassium chlorate and sugar is added to the water and absorbed into the napkin. The napkin is dried. The dried napkin is glued to the glass bottle containing the sulfuric acid and gasoline mixture. When the thrown bottle is broken, the sulfuric acid reacts with the potassium chlorate in the napkin and ignites[5].

In our study, the burning properties of molotov cocktails will be seen. How long the burning continues, the spread of the fire and the burning temperature it reaches will be measured. It will be seen whether the additional substances mixed into the Molotov cocktail content increase the damage to the environment. The change of parameters with the effect of the surfaces of Molotov cocktails broken on 5 different surfaces will be determined. In addition, the changes in the extinguished molotov cocktails will be evaluated. Based on this study, it is aimed to explain the following issues about the molotov cocktail: Is the molotov cocktail a bomb? Do healthcare workers recognize the molotov cocktail? What injuries can a Molotov cocktail cause?

Materials and Methods

Various Molotov cocktails were prepared with easily available detergents, hand soap, eggs, cologne, resin, nails, thinner, glue, waste oil, bleach, paraffin and sugar. The effect areas, burning times and properties of these Molotov cocktails were determined (Table 1). 'Testo' branded thermometer was used. Molotov cocktail was prepared with brown beer bottles with a glass thickness of 0.3 cm. Molotov cocktails were thrown freely by the same person to experience the street actions. The amount of material in the Molotov cocktail has been determined by utilizing the experiences of bomb experts. However, the amount of content of these molotov cocktails, which are prepared even by children in most countries, is not fixed. The experiment was conducted within the scope of a project supported by DUBAP (Dicle University Scientific Research Projects Coordinatorship). During the experiment, the contributions of the Diyarbakır Bomb Disposal Directorate, Diyarbakır Fire Department and Diyarbakır AFAD were received.

Table 1. *The materials of the mixtures, the amounts added and how many Molotov cocktails were made are shown.*

Material		How many (%)
Gas Only	110-220-330 ml	9 (10,5%)
Waste oil	50 ml (with 150 ml gasoline)	8 (9,3%)
Thinner	120 ml (with 150 ml gasoline)	6 (7%)
Candy	40 gr (with 150 ml gasoline)	9 (10,5%)
Cologne	120 ml (with 150 ml gasoline)	8 (9,3%)
Rosin	10 ml (with 150 ml gasoline)	10 (11,6%)
Paraffin	50 gr (with 150 ml gasoline)	4 (4,7%)
Egg white	10 gr (with 150 ml gasoline)	7 (8,1%)
Liquid soap	40 ml (with 150 ml gasoline)	6 (7%)
Bleach	50 ml (with 150 ml gasoline)	4 (4,7%)
Detergent	40 gr (with 150 ml gasoline)	6 (7%)
Glue	15 ml (with 150 ml gasoline)	7 (8,1%)
Soap and Sugar	40ml, 40gr (with 150 ml gasoline)	2 (2,3%)
Total	86 (100%)	

All the data obtained as a result of our study were analyzed using the SPSS Statistics 24.0 package program. Descriptive statistics, frequency calculations, Chi-square, nonparametric tests and Kruskal Wallis test calculations were made.

Results

35 (40.7%) of 86 Molotov cocktails could not be broken, and 51 (59.3%) of them were broken. Our broken Molotov cocktails immediately caught fire. The most effective parameter in breaking the glass bottles was the type of surface. In the Chi-square analysis between the fractured status and the surface type, $p=0.000$ was found to be significant. In other surfaces (soil, gravel) that have the properties to absorb the force, the fracture has not been fully achieved. In other words, for the Molotov cocktail to start a fire, it must be broken on hard surfaces such as concrete, metal and cars.

The average burning temperature of our Molotov cocktails, which were broken on all surfaces, was 350 °C. The highest combustion temperatures were achieved with molotov cocktail mixtures containing resin, paraffin, and glue. The contents of Molotov cocktails were compared with the combustion temperature, burning time, type of ground, amount of gasoline, and splash distance. In the Kruskal Wallis test analysis, significance was found between combustion temperature and burning times with some molotov content. (Table 2).

***Table 2.** Kruskal Wallis test analysis was performed. Significance was found between combustion temperature and burning times with some molotov contents. A multiple comparison test was performed between the parameters found to be significant.*

	Gasoline	Temperature	Duration	Diameter	Ground Type
Ki Kare	4,075	34,884	21,026	8,452	13,890
Df	12	12	12	12	12
Asymp. Sig.	,982	,000	,050	,749	,308

Multiple comparison analysis was performed between nonparametric independent samples to determine the significant mixture contents. The Box Plot graph, which includes the analysis of combustion temperature and cocktail contents, is shown below (Figure 1). It is seen in the graph that the highest combustion temperatures are reached in mixtures containing gasoline, resin, paraffin, soap-sugar, and glue. It was observed that the combustion temperature of mixtures containing thinner, sugar, resin, paraffin, soap, bleach, liquid soap-sugar, detergent, and glue was in a narrow range. In addition, it has been observed that they can reach similar temperatures in each combustion. Combustion temperatures of mixtures containing waste oil, cologne, and eggs are distributed over a wider range. The lowest combustion temperatures were observed in molotov cocktail mixtures containing sugar-gasoline. The factors affecting the combustion temperature change are mentioned in the discussion section.

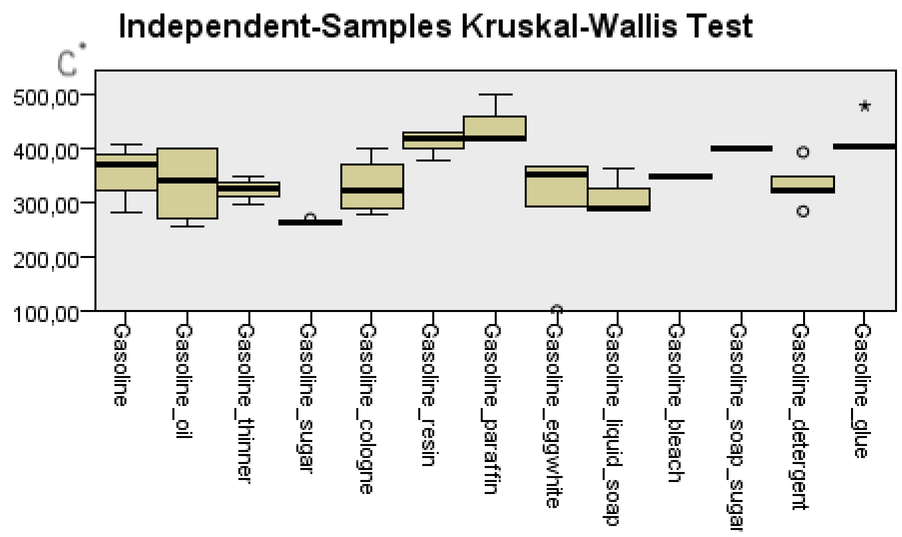

***Figure 1**. Multiple comparisons between Temperature and Independent samples, Kruskal Wallis Test, Box Plot graph. *Total N(Fractured)=51, Test Statistic=34,884, Asymp Sig.(2-Test)=,000*

The average burn time we achieve in all our Molotov cocktails is 192 seconds. The combustion duration was affected by parameters such as the wind in the air, the ground and the added material.

In the Chi-square statistical analysis, significance was found between the change in Molotov cocktail content and the burning time (Table 2, Asymp, Sig.=0.50). Multiple comparison analysis was performed to determine the significant items. Multiple comparison analysis was performed between the burn time and independent samples using the Kruskal-Wallis Test. The created Box Plot graphic is given in Figure 2. It is seen in the graph that the longest burning time is in Molotov cocktails containing glue, paraffin, and oil. The median values of most mixtures are close to each other. The burning times of cocktail mixtures containing thinner, resin, egg, soap, and soap-sugar are in a narrow range. The burning times of the other mixtures showed a wide range.

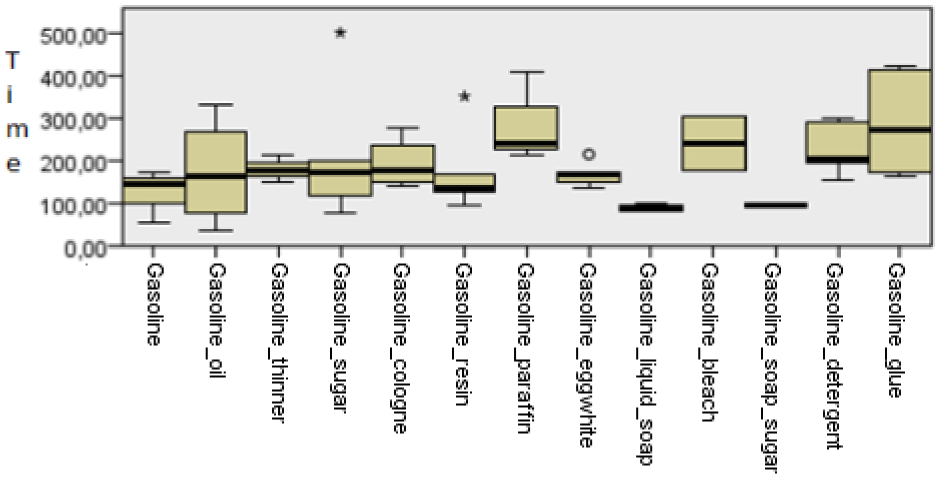

Figure 2: *Multiple comparisons between Time and Independent samples, Kruskal Wallis Test, Box Plot graph. *Total N(Fractured)=51, Test Statistic=21,026, Asymp Sig.(2 Test)=,050*

The maximum diameter at which the flame spread was measured with the help of a meter. The highest splash distances were seen on the concrete floor which was hard and transmits the force as well.An American cloth was hung on the wall and Molotov cocktails were thrown at certain distances (1-2-3-4 meters). It has been seen from which distances the splashing flame can burn the cloth. In 50% of Molotov cocktails thrown at a distance of 4 meters, the flames spread to the cloth, but it did not create enough effect to ignite the cloth. In 50% of Molotov cocktails thrown 3 meters away, the flames spread to the cloth and ignited the cloth. Burning American cloth has been replaced. Molotov cocktails were thrown at distances of 2 meters and 1 meter. All Molotov cocktails broken at both distances caused burns in the cloth.

Discussion:

It has been determined in our study that the combustion temperature and burning time can be increased by strengthening the Molotov cocktail content. As the burning temperature and duration increase, the destruction of the fire also increases and it becomes more difficult to extinguish. Fire contact with humans is dangerous at these high temperatures. May cause severe burns to tissues.A fire created by a Molotov cocktail; According to studies, it can be extinguished in less than 5 seconds with the use of fire extinguishers[2]. For this reason, the damage caused by the Molotov cocktail can be minimized by quick extinguishing interventions and first aid.

Gasoline is a rapidly, highly flammable, and highly volatile substance. It has a long burning time because it consists of different components with boiling points ranging from 32 to 204°C [6]. It is preferred as an accelerator by 75% of those with the aim of arson [7]. In addition, due to its high volatility, a large amount of evaporated gasoline creates a flammable gas zone in the combustion area. This flammable gas zone makes the dispersal of the fire and the ignition area unpredictable [8]. Gasoline is an apolar molecule. Intra-inter molecular forces occur when the substances added to the gasoline are polar or nonpolar. These forces affect the combustion temperature and combustion times. In a study with chemical Molotov cocktails in Spain, sugar was added to mixtures to exothermic reactions and cause stronger, longer burning [5]. In this study, the sticky surface prolonged the burning time of the Molotov cocktail prepared with sugar mixture. Burning times were measured to be above the average burning time of other Molotov cocktails.

Epoxy resin is a synthetic, high molecular weight, thermoset polymer group macromolecule. Its carbon-rich structure allows it to burn easily and well. When a polymer is heated, its chains begin to break down, resulting in volatile fuel molecules [9]. For this reason, large polymers such as epoxy resin are expected to burn similarly to polyvinyl ester groups [10]. As expected, Molotov cocktails containing an epoxy resin-gasoline mixture could reach similar combustion temperatures with glue-gasoline mixtures during combustion. In the mixtures containing resin, high combustion temperatures were reached during each combustion and it was observed that the temperature range was narrow. Burn time was also found in a narrow range.

Wood glue is polyvinyl acetate[11]. These carbon-rich compounds burn well and produce an exothermic reaction. For this reason, higher combustion temperatures have been achieved in our molotov cocktails containing wood glue. The longest burning times were observed in our mixtures containing glue. In addition, when this Molotov cocktail was extinguished, a white residue was detected on the floor.

Paraffin is an alkane with 26-30 carbons and is apolar[12]. The combustion of paraffin alone is an exothermic reaction, so it raises the ambient temperature as the mixture burns. The highest burning temperature and burning time were observed in the molotov cocktail mixture with paraffin added. In addition, the thrown Molotov cocktails formed a sticky layer on the combustion floor. It is thought that the purpose of using paraffin is to increase the destruction by providing adhesion, long burning, and high temperature.

Liquid detergent and solid detergent contain hydrophilic and hydrophobic groups. In other words, detergents contain both polar and nonpolar parts. Detergents do not contain molecules from the flammable group [13]. For this reason, it is thought that the burning temperature and burning times of Molotov cocktails containing detergents are below the average measurements.

The sodium hypochlorite in bleach is not a combustible substance on its own, it is a strong oxidizer. Fumes from a mixture of sodium hypochlorite and gasoline during combustion can be highly toxic; Hazardous substances such as chloroform, dichloromethane, and hydrochloric acid can be produced [14]. During the experiment, it was observed that a gas was produced when we mixed gasoline and bleach. An above-average burning temperature and burning time were measured in Molotov cocktails containing bleach.

Waste oil is a nonpolar molecule[15]. The non-polar gasoline and oil have become a homogeneous mixture. In these Molotov cocktails, the average burning temperature was 335°C and the burning time was 171 seconds. The oil kept the ambient temperature high with exothermic combustion and increased the ambient temperature. In addition, due to the non-volatility of the oil, the burning time is longer than in some mixtures.

Thinner is a nonpolar molecule and has high volatility[16]. It creates a homogeneous mixture with nonpolar gasoline. Although it has high volatility, the average combustion temperature was 323 °C and the burning time was 178 seconds.

Cologne is a polar molecule[17]. It has been observed that it can be temporarily dispersed in gasoline with quick agitation. Cologne is a flammable, highly volatile, and flammable substance, so the average burning temperature and burning times have been reached.

The average burning temperature and burning time of the other Molotov cocktails were below the mixtures with egg white added. Egg white formed a sticky and flammable layer on the floor. When extinguished, the viscous structure of the egg left a white residue.

Combustion times are not directly proportional to the fact that the substance in the mixture contains flammable molecules. Because the unit amounts of the added substances in the distribution were not kept equal. The amount of the substance was determined by the information received from the security forces. For example, 10 ml of epoxy resin and 15 ml of wood glue are used in our mixtures. The resin should burn similarly to the polyvinyl ester groups [18]. However, the burning time of the mixtures containing wood glue could not be reached. Because the quantities are different. The change in carbon numbers per unit amount also affects combustion times. It has been determined in our study that the combustion temperature and burning time can be increased by strengthening the Molotov cocktail content. As the burning temperature and duration increase, the destruction of the fire also increases and it becomes more difficult to extinguish. Fire contact with humans is dangerous at these high temperatures. May cause severe burns to tissues.

Limitations of the Study

It is the first study in its field on the Molotov cocktail. For this reason, comparison and discussion could not be done sufficiently. In addition, explosives were not used in our study. The residues formed as a result of combustion and their chemistry have not been studied.

Conclusion

Molotov cocktails are known for their association with civil unrest and violent protests and are still widely used as incendiary weapons in various conflicts and riots [19]. As we experienced in our study, a Molotov cocktail is an improvised incendiary device, unlike an IED (improvised explosive device). Considering the damage it causes and the stress it creates on the public conscience, the Molotov cocktail can act like a weapon. Therefore, crimes committed with a Molotov cocktail should be punished as if committed with a weapon.

A study was conducted on thermal protective fabrics exposed to Molotov cocktails, evaluating the physical properties and protective performance of the fabrics when exposed to fire generated by simulated Molotov cocktails [20]. This research contributes to the understanding of the effectiveness of protective clothing materials in mitigating the effects of Molotov cocktails on various surfaces. In our study, the fires caused by Molotov cocktails reached temperatures that could cause severe burns. Such research provides valuable information for improving fire safety measures and developing strategies to reduce the impact of incendiary devices such as Molotov cocktails.

In situations of ethnic riots or civil unrest, Molotov cocktails can increase tensions and civilians may resort to arming themselves with such weapons as a means of protection [21] . The use of Molotov cocktails for this reason not only poses a threat to law enforcement, but also endangers the lives of those involved, potentially causing serious burn injuries [20.] Moreover, Molotov cocktails have been used by various groups for different purposes, including terrorist activities. For example, documented cases include attacks on financial institutions and symbolic landmarks [22]. The use of Molotov cocktails in such scenarios shows that they are used not only as a means of protest, but also as a means of terror and repression.

In forensic medical cases, it is very important for healthcare professionals to determine the difference between a bomb injury and a Molotov cocktail injury in order to determine the nature of the crime. Bombs can cause explosive or shrapnel injuries, while handmade incendiary Molotov cocktails cause burn injuries. These issues should be taken into account when preparing the report in forensic cases. In addition, ingredients added to the Molotov cocktail mixture can be detected in samples taken in laboratories. Attention should be paid to whether substances that increase the destruction of the Molotov cocktail are used. If this is detected, the penalty for the offense should be increased.

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