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An Unconventional Two-Stage Push-Button Common Discharge Mechanism for Fire Extinguishers

Anshumaan Krishnan Ayyangar[1], Shital V. Patel[2]

[1]*Postgraduate Student, Dept. of Mechanical Engineering, Bharati Vidyapeeth College of Engineering, Navi Mumbai, MH, India*
[2]*Asst. Professor, Dept. of Mechanical Engineering, Bharati Vidyapeeth College of Engineering, Navi Mumbai, MH, India*

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Abstract - *Firefighting requires accurate and timely reaction towards a distress call based anywhere near or far. Part of the accuracy and swiftness of extinguishing action involves the correct handling of the equipment and quick actuation of the discharge mechanism – manual or automatic (drone deployment, etc.). Safety regulations and protocols mandate the usage of a pin or a lever guard clip in conventional extinguishers. The two-stage push-button mechanism eliminates the need for such additional components in the overall assembly and encourages minimalistic design, thereby facilitating a simple, reflexive and schematic method to fight fires. This is done to increase the product's usability, functionality, and reliability.*

Key Words*:* **firefighting; extinguisher; discharge; push-button; two-stage; drone; unconventional; usability; functionality**

1. INTRODUCTION

A fire can start in expected or unexpected situations, and requires a meticulous and effective approach to douse it. First responders usually take some time to arrive on scene and carry out countermeasures, but there are basic firefighting equipment available in almost all places. Fire extinguishers are widespread safety devices used to extinguish small fires or before those go on to become large ones. Despite certain mandates, the intended user (the general public) often does not understand how a fire extinguisher functions; neither can the user differentiate between the different kinds, which can lead to mistakes in use [1]. That said, humans have shown, by facts, figures and argument, that a large proportion of all the fires that occur could, by such means, be extinguished before extensive damage occurs [2].

A simple representation of a commercial fire extinguisher was made by a teacher from Commercial High School, Brooklyn, N.Y., U.S.A. in 1914, to depict the simple science behind its working. The following diagram shows a simple fire-extinguisher for demonstration purposes which is designed to the end that the visibility disadvantages can be readily overcome for learning purposes [3]. This was the first instance of common people figuring out the mechanism behind the discharge of the extinguishing elements present inside the cylinder (soda-acid extinguisher), using which other types of extinguishers were benchmarked and modeled.

Fig -1: Theodore Cohen's 'Visible' Educational Fire Extinguisher [3]

Any fire has three elements that act as necessary ingredients – heat, fuel and an oxidizing agent (mostly oxygen). These form the Fire/Combustion Triangle as shown below.

Fig -2: The Fire/Combustion Triangle

A Fire/Combustion Tetrahedron includes the effect of a chain reaction to the existing ingredients, as sometimes, it becomes crucial to also consider the energy release (in case of burning metals, etc.). It is depicted as follows.

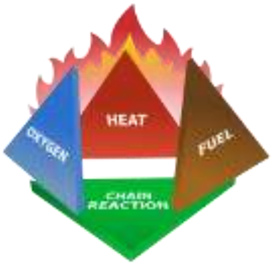

Fig -3: The Fire/Combustion Tetrahedron

An extinguisher should optimally keep a constant pressure to emit the extinguishing agent at a proper temperature and to emit proper quantity of extinguishing agent to extinguish fire [4]. This also means that the equipment should be operated properly under all conditions. Firefighters exert themselves to maximal levels while fighting fires. Aerial ladder climbing, dragging hose, carrying the travelling ladder, victim rescue, and raising the ladder are among the most strenuous tasks, in declining order of energy demand. Under fire conditions, these physical demands are complicated by the metabolic demands of coping with heat and loss of fluids. The combined effect of internally generated heat during work and of external heat from the fire may result in markedly increased body temperatures that climb to unusually high levels in an intense firefighting situation [5]. At present, each cylinder is clearly labelled with the name of its contents, and cylinders are distinctively coloured to distinguish one type from another [9]. To reduce further ergonomic difficulties, a two-stage push-button type discharge mechanism is ideated to ease the firefighting experience and make it simplified and uniform across various classes of fire.

2. CLASSES OF FIRE

Fires correspond to various classes based on occurrence and have respective types of extinguishers used to curb them, which perform specific functions. They are explained in two different graphics as follows.

Type	CLASS A	CLASS B	CLASS C	CLASS D	Electrical	CLASS F	Comments
	Combustible materials (e.g. paper & wood)	Flammable liquids (e.g. paint & petrol)	Flammable gases (e.g. butane and methane)	Flammable metals (e.g. lithium & potassium)	Electrical equipment (e.g. computers & generators)	Deep fat fryers (e.g. chip pans)	
Water	✓	✗	✗	✗	✗	✗	Do not use on liquid or electric fires
Foam	✓	✓	✗	✗	✗	✗	Not suited to domestic use
Dry Powder	✓	✓	✓	✓	✓	✗	Can be used safely up to 1000 volts
CO2	✗	✓	✗	✗	✓	✗	Safe on both high and low voltage
Wet Chemical	✓	✗	✗	✗	✗	✓	Use on extremely high temperatures

Fig -4: Types of Fire; Classes and Suitability of Fire Extinguishers

Fig -5: Functions of Different Types of Fire Extinguishers © Blackwood Fire

3. EXISTING FIRE EXTINGUISHER DESIGNS

Water-Based Fire Extinguisher

Water fire extinguishers, which are the most common, are essentially tanks full of water with compressed air as the propellant to make them come out. Water extinguishers work by removing heat from the fire [6].

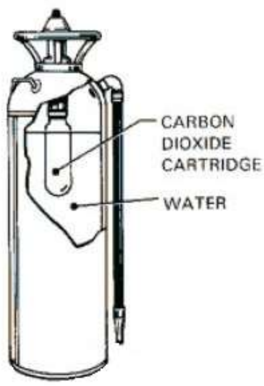

Fig -6: Water Fire Extinguisher [10]

Foam-Based Fire Extinguisher

This extinguisher type consists of two containers - the outer one is filled with water, whereas the central one has carbon dioxide charge and foam solution. The central container has a plunger mechanism at the top which when depressed releases the carbon dioxide and allows foam and water to mix. The foam and water comes out of the nozzle, creating mechanical foam. This extinguisher is operated in upright position [10].

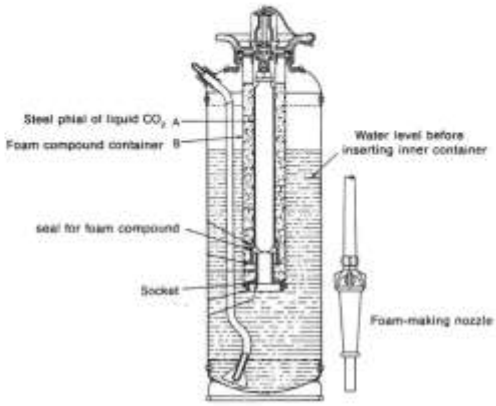

Fig -7: Foam Fire Extinguisher [10]

Dry Powder-Based Fire Extinguisher

Dry powder fire extinguishers are cylinders of foam or dry powder with compressed nitrogen or carbon-dioxide as the propellant. They work by smothering the fire [6]. Here, sodium bicarbonate powder is used to extinguish almost all types of fires [10].

Fig -8: Dry Powder Fire Extinguisher [10]

CO2-Based Fire Extinguisher

CO_2 fire extinguishers contain a mixture of liquid and gaseous carbon-dioxide, which is a non-flammable gas. CO_2 is normally a gas at room temperature and pressure. It has to be stored under high pressure to make it a liquid. When the pressure is released, the gas expands enormously and makes a huge white jet. CO_2 attacks the fire triangle in two ways: it smothers the oxygen and, when it turns from a liquid back to a gas, it sucks in a massive amount of heat from its surroundings, which cools whatever it is sprayed on by removing heat [6].

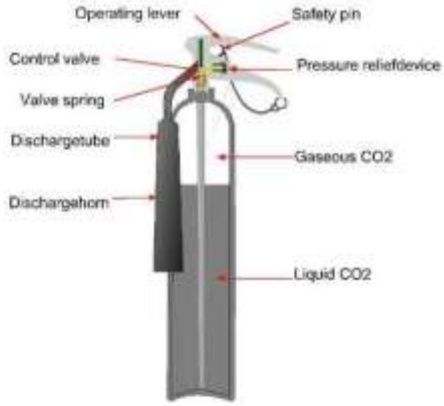

Fig -9: Carbon-dioxide Fire Extinguisher [10]

Wet Chemical-Based Fire Extinguisher

Sodium bicarbonate (soda) and sulphuric acid are the prime components of this extinguisher. They combine to form a chemical reaction to produce CO_2 gas, which is used to smother the fire. The arrangement of the extinguishers comprises of a container which holds the sodium bicarbonate solution, and a small glass bottle (phial) containing sulphuric acid is placed below a plunger mechanism, which is covered by a safety glass along with a screw and cap at the top. When the plunger is struck, the glass bottle breaks, resulting in mixing of acid and soda. A chemical reaction takes place which produces CO_2 gas. The carbon dioxide gas pressurizes the space above the liquid (used for extinguishing fire) and forces it out through the internal pipe of the nozzle [10].

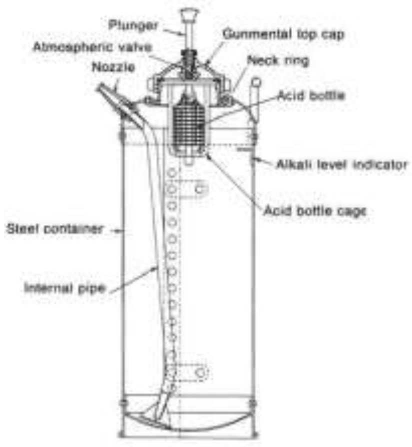

Fig -10: Wet Chemical Fire Extinguisher [10]

4. COMMON TWO-STAGE PUSH-BUTTON DISCHARGE MECHANISM DESIGN

Bearing in mind the standard plunger dependency involved in all discharge mechanisms, the following are the steps involved in the process:

1. Pressure gauge is checked for any discrepancies.
2. Safety pin/clip is removed from the discharge apparatus.
3. Discharge lever/squeeze grip is engaged/pressed.
4. Plunger is pushed inside.
5. One of the following steps ensues – the cartridge seal is broken (or) extinguishing agent rises in the tube due to compression pressure.
6. The agent is discharged from the cylinder via the tube nozzle/horn.

The new design intends to fuse steps 1, 2 and 3 into a single common step, thereby reducing the reaction time and complexity behind the process and facilitating a simple, reflexive and schematic method to fight fires. This is done to increase the product's usability, functionality, and reliability. It needs to be noted that a push-button mechanism already exists for fire extinguishers {refer Fig. (11)}, but it is a single-stage based design and has noteworthy safety and performance issues. This new design also aims to eliminate such issues by improving on the aforementioned model's safety parameters without compromising on the standard equipment's efficiency.

Fig -11: Conventional Lever and Push-Button Fire Extinguisher Heads [11] © Kidde Corporation

5. PRELIMINARY DESIGN CONCEPT

Fig. (12) shows the working of an existing single-stage push-button fire extinguisher. It follows a binary approach, i.e., discharge when pressed and no discharge when released. The absence of an intermediate stage eliminates any assurance of safety and also puts unnecessary ergonomic stress on the operator's finger, thereby reducing their working efficiency by hampering the duration of their firefighting alertness.

This design has modular discharge architechture, i.e, the high-pressure canister inside the cylinder and the exhaust unit are two separate entities and can be assembled or disassembled individually.

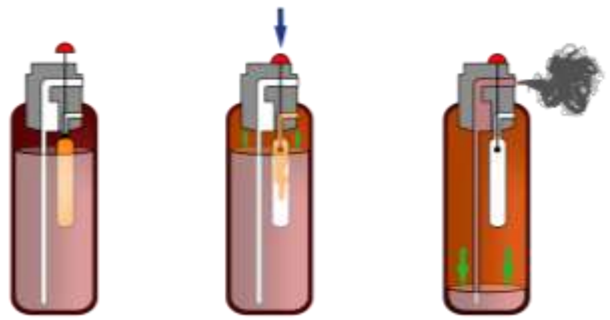

Fig -12: Working of a Sample Single-Stage Push-Button Extinguisher

Fig. (13) shows a modification proposed for the discharge unit to accommodate the two-stage mechanism to eliminate the former's downfalls, and also extend its usage to automatic firefighting applications (for example, using drones).

This design has integral discharge architechture, i.e., the high-pressure canister inside the cylinder and the exhaust unit are assembled and disassembled as one common entity.

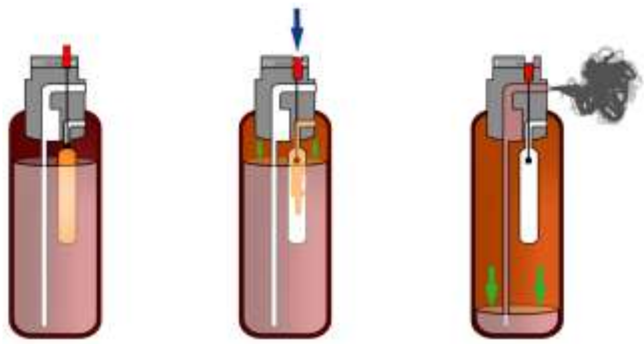

Fig -13: Proposed modification for intended applications

It consists of a spring-loaded mechanism meant to hold the plunger button in place once pressed completely, i.e., past both stages. This makes manual and automated processes much easier and directs the entire effort of the firefighter to the hose.

It needs to be noted that although the design is integral, the holding rod and its spring can be reset and the unit can be reused by just replacing the punctured high-pressure canister.

6. MATERIAL SELECTION

Various materials are used in the new design for the functional parts depicted in the assembly. Materials required for the parts involved in the proposed discharge mechanism are chosen using Ashby Charts (different charts for different parts, based on application):

- Push-button
- Plunger rod
- Plunger cavity
- Holding rod spring
- Holding rod
- Discharge unit casing
- High-pressure canister
- Nozzle
- Discharge valve spring
- Discharge valve

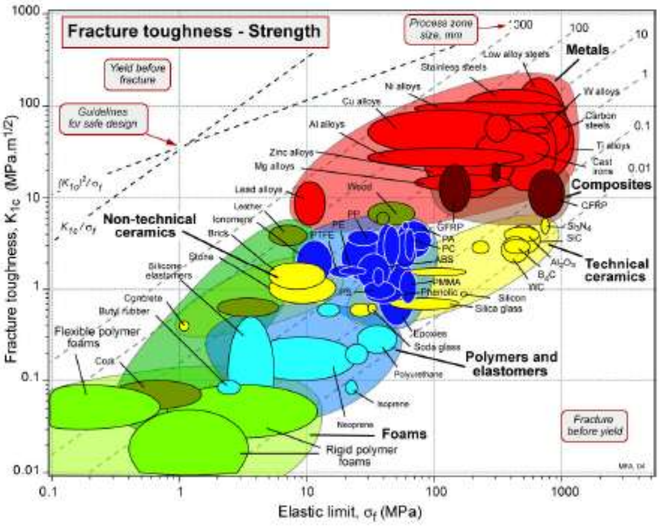

Chart -1: Ashby's Fracture Toughness vs. Strength Chart [12]

The Fracture Toughness vs. Strength Chart is used for components that do not have major movements, but are prone to fatigue and fracture due to the stresses acting on them. These are as follows:

- Plunger cavity
- Holding rod
- Discharge unit casing
- High-pressure canister
- Nozzle

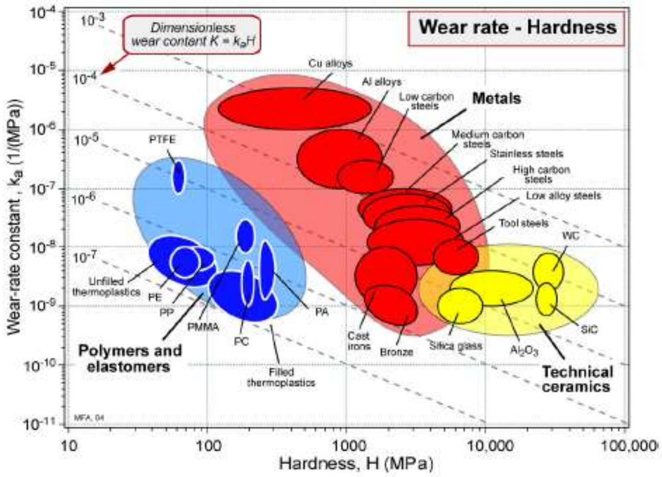

Chart -2: Ashby's Wear Rate vs. Hardness Chart [12]

The Wear Rate vs. Hardness Chart is used for components which are prone to more movement, and therefore, more wear and tear. This includes the following:

- Push-button
- Plunger rod
- Holding rod spring
- Discharge valve spring
- Discharge valve

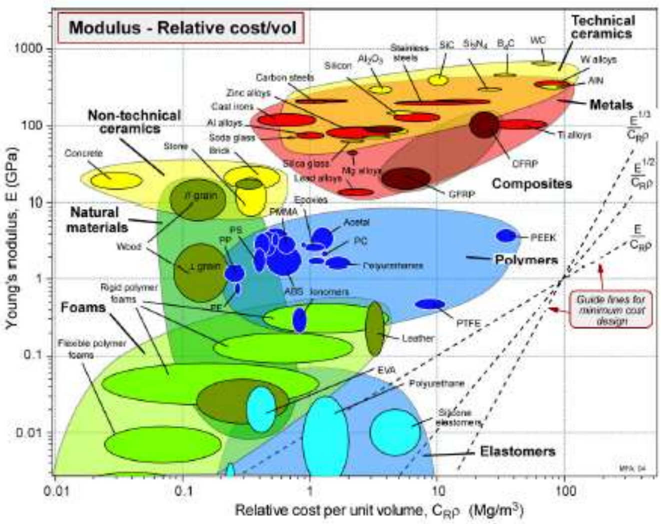

Chart -3: Ashby's Young's Modulus vs. Relative Cost/Volume Chart [12]

The Relative Cost vs. Volume Chart is meant for both the aforementioned types of components to decide the final material out of a group of materials, for the required volume and its market cost per unit. This is done to reduce the overall price of the extinguisher and also reduce its overall weight, if possible. The outcomes of the same are observed in the ergonomic and economic advantages. The following are the chosen materials:

Table -1: Materials Proposed*# for Various Components

S. No.:	Material Selection Details		
	Component	***Material Type***	***Material Name***
1	Push button	Polymer	HDPE
2	Plunger rod	Metal	/Stainless Steel
3	Plunger cavity	Metal	/Stainless Steel
4	Holding rod spring	Composite	/Hardened Beryllium Copper
5	Holding rod	Polymer	HDPE
6	Discharge unit casing	Polymer	APO^ coated PVC
7	High-pressure canister	Metal	Aluminium
8	Nozzle	Polymer	APO^ coated ABS-FR
9	Discharge valve spring	Metal	Stainless Steel
10	Discharge valve	Metal	/Chrome plated Brass

*materials were chosen after careful consideration of the abscissa and the ordinate parameters of each chart for the respective component and its working environment using theoretical trial-and-error method.

#material types are colour-coded as per the Ashby Chart representation.

^APO = 1-aziridinyl phosphine oxide: a resin forming polymer.

7. DETAILED DESIGN MODEL

Taking the preliminary design concept and the materials' analyses using Ashby Charts into consideration, the detailed design model has been ideated. This design incorporates both external and internal safety by accommodating the two-stage push button mechanism (exterior) and the corresponding poppet ball seat valve mechanism (interior). The following is the diagram of the discharge unit representing the initial (Fig. 17(a)), intermediate (Fig. 17(b)) and final stages (Fig. 17(c)):

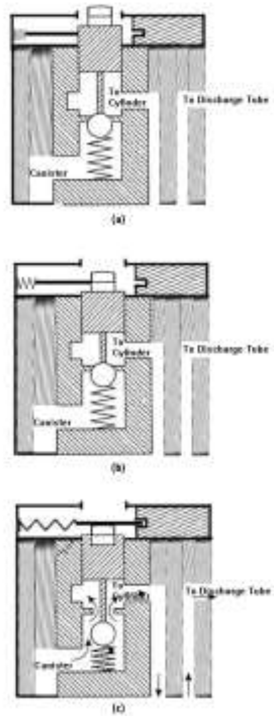

Fig -14: Proposed Two-Stage Push Button Discharge Mechanism

Table -2: Cylinder Properties Comparison

S. No.:	Cylinder Properties		
	Characteristics	**Existing (sample)**	**Proposed (concept)**
1.	Capacity (kgs)	6	6
2.	Avg. Charged Weight (kgs)	10.3	9.3
3.	Operating Pressure (psi/bar)	195/13.4	195/13.4
4.	Range (metres)	5-7	5-7
5.	Avg. Discharge Time (secs)	23	25
6.	Height (cms)	54.6	55.4
7.	Cylinder Diameter (cms)	15.2	15.2
8.	Overall Width (cms)	26	26
9.	Media	ABC	ABCDEF
10	Guaranteed life	10	12

S. No.:	Cylinder Properties		
	Characteristics	Existing (sample)	Proposed (concept)
	period (years)		
11.	Avg. Operating VAS Pain Scale Value (out of 10)	5	4
12.	Torque* from Ulnar Deviation of User's Wrist (Nm)	8.0834	1.8247

Table colour codes: Red = Impediment; Yellow = No change; Green = Improvement.

Simulative data calculated and established using SIEMENS PLM Software.

*Torque = F x d = m x g x d.

Table II compares the properties of the existing and proposed models, denoting nominal, ordinal, discrete and continuous data. The benefits or lack thereof of the new concept can be observed from the same. In Table I, the materials with a '/' before their names have been unchanged from the existing design.

The major assist of the push button – the spring based holder mechanism – keeps the discharge setup engaged throughout until it is reset, thereby making it convenient for the user to use the fire extinguisher. This model can be manually operated or left for actuators in automatic applications (such as drone firefighting, etc.) to exploit its ease of usability, thereby ensuring optimum, swift, safe and focused firefighting.

8. CONCLUSIONS

After the proposed design modifications were made, the fire extinguisher has a bettered ergonomic efficiency due to the loss of weight by 9.71 (~10) % and elimination of stress on the operator's hand due to the improved discharge mechanism model by drastic reduction of torque-induced Ulnar deviation {Ref. (Table II)}. The implementation of polymers and composites along with metals have ensured that the costs incurred have come down fractionally.

Out of the 12 characteristics taken for comparison in Table II, 6 have seen improvements, 5 have been unchanged, while only 1 has seen an undesired outcome. Thus, the proposed design significantly improves the existing one by the following parameters:

TANGIBLE

- Promotes minimalistic design
- Eliminates excess moving components in the assembly
- Improves safety of design
- Reduces the overall charged weight of the extinguisher cylinder
- Marginally improves the average discharge time
- Accommodates all media (classes) of fire in a common design
- Encourages a schematic and reflexive firefighting process

INTANGIBLE

- Reduces ergonomic stresses on the user
- Ease of usability
- Increases the guaranteed life period
- Adheres to all existing norms, rules and regulations despite undergoing change in design

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