International Journal of Innovative Research & Growth
E-ISSN: 2455-1848
homepage: http://www.ijirg.com/ijirg/
Volume: 14 Issue: 2, April 2025

Bypass Valve Integration in CO_2 Fire Suppression: Ensuring System Continuity Under Failure Conditions

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KEYWORDS

CO_2 Fire Suppression Systems, Critical Infrastructure Protection, Electronic Equipment Safety, Non-Conductive Fire Suppression, Oxygen Displacement, Mechanical Bypass Valve, Manual CO_2 Release, System Redundancy.

ARTICLE DETAILS

Received 13 February 2025; revised 27 March 2025; accepted 04 April 2025

DOI: 10.26671/IJIRG.2025.2.14.113

CITATION
Tiwari, V., Kushwah, N. S. (2025). Bypass Valve Integration in CO_2 Fire Suppression: Ensuring System Continuity Under Failure Conditions. *Int J Innovat Res Growth*, 14(2), 14222-14227. DOI

Abstract

Essential infrastructure safety calls for CO_2 fireplace suppression structures, specifically in settings with delicate electronic gadget wherein water-based totally suppression systems are irrelevant. those structures provide clean, residue-free, non-conductive fire protection via displacing oxygen to prevent combustion. however, due to the fact they rely on electronically controlled activation mechanisms, they're prone to electrical faults, factor screw ups, and electricity outages. A automatically actuated pass valve has been used as a fail-secure approach to conquer those troubles. The layout, operation, and integration of the pass valve into contemporary CO_2 systems are tested on this paper. by means of bodily fending off automatic controls, the skip valve lets in manual CO_2 release, ensuring fireplace suppression even in the occasion of a total machine failure. The valve's capacity to make sure continuous fireplace safety changed into confirmed thru experimentation. as a way to improve the resilience, dependability, and protection of CO2 fireplace suppression systems, the take a look at emphasizes the need of redundancy in fireplace protection layout and offers best practices for the usage and maintenance of pass valves.

1. Introduction

Fireplace manage, suppression, and extinguishment are examples of energetic fireplace protection structures. despite the fact that general extinguishment might also nonetheless necessitate private intervention, fire manage, together with sprinkler systems, attempts to restrict hearth boom and save you flash-over. [7] whilst fireplace extinguishment absolutely puts out the fire and forestalls it from beginning once more, suppression targets to hold the hearth from getting worse. so as to unexpectedly suppress and positioned out fires, even in hidden places, CO_2 hearth suppression systems use general flooding, [3] which releases CO_2 fuel via nozzles. CO_2 is a residue-loose, non-conductive agent this is perfect for safeguarding delicate electronic gadgets. it is a beneficial and hygienic choice for high-danger conditions considering that it is mainly accurate at setting out elegance A and class C fires without de-energizing electrical circuits. [8] however, in conditions where the strength cannot be reduced off, protection must be provided, and the effectiveness of CO2 on those flames needs to be carefully considered. For electrified electrical device, the high-quality design for CO2 hearth extinguishing systems relies upon on:

1. Identifying the hazard that needs to be protected.
2. Determining the proper design specifications.

Determining the sort of electrical equipment, the worst-case expected energy level, and the type of undesired fire that may need to be controlled are all part of defining the danger. Determining the CO_2 extinguishing concentrations required for efficient fire suppression is the primary step in establishing the proper design parameters.

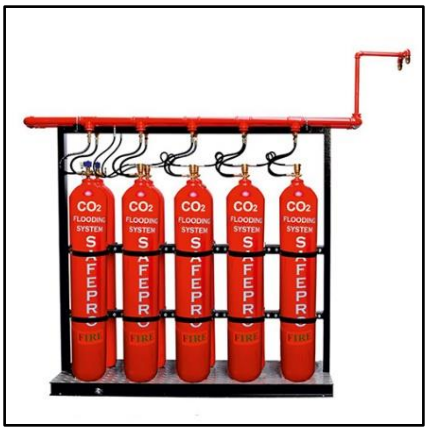

Fig.1: Basic Structure of System [10].

2. Literature Review

Jun Guo et.al 2024 [1] This study critiques CO_2-based totally hearth prevention in coal mines, highlighting its inerting and cooling advantages. It examines CO_2's houses, extinguishing mechanisms, pipelines, and monitoring systems. Addressing confined subject expertise, it gives a theoretical foundation to improve the sensible, green, and safe utility of CO_2 hearth manage technology.

Olga Gaidukova et.al 2022 [2] This examine explores CO_2 hydrates in powder and pill shape for suppressing liquid fuel fires. Powdered granules proved 20 instances extra green than pills. rapid CO_2 launch displaced oxidizers, successfully extinguishing flames. in comparison to other retailers, hydrates confirmed advanced fire suppression and capacity for lowering combustion-associated emissions.

Kamal Shukla et.al 2021 [3] This paper explores the usage of an IG-fifty-five easy agent flooding device for server room fire safety. It highlights its effectiveness, protection, and suitability for sensitive environments, providing a higher alternative to water-based totally systems. regardless of better charges, it guarantees gadget protection and offers precious enjoy in superior fireplace suppression era.

A. Dinesh et.al 2020 [4] This has a look at determines nitrogen's required design attention for aircraft fireplace suppression, changing Halon 1301. CFD simulations and experimental assessments found 34–39% nitrogen (thirteen–14% oxygen) needed to extinguish fires. Nitrogen requires 7.5 instances more mass than Halon. destiny paintings include MPS trying out for plane cargo and engine bay safety structures.

Li Tang et.al 2019 [5] A 1:1 CO_2–N_2 composite inert gasoline turned into injected into the Tangkou coal mine's goaf to control spontaneous combustion. It extensively decreased CO tiers inside nine days even as keeping CO_2 below safety limits. price-effective and more secure than pure CO_2, it offers a sensible answer for lengthy-term fireplace prevention.

JOSEPH Z. SU et.al 2001 [6] hearth suppression assessments the use of IG-01 (argon) and IG-541 discovered that both sellers extinguished fires via lowering oxygen ranges. larger fires have been less difficult to suppress. IG-541 allotted uniformly, making sure constant overall performance, even as argon showed stratification. IG-541 proved extra dependable for numerous fires loads due to its better dispersion.

3. Problem Identification

Without a dependable and redundant backup, a CO_2 hearth suppression gadget offers serious operational and protection hazards, in particular in settings where gadget integrity is important. these hazards are most major whilst there are electricity outages, damaged electrical cables, or dead batteries. The gadget is vulnerable to general failure in emergency conditions while its far maximum wished if it best uses electrically activated parts, which include solenoids, strain launch valves, or manipulate panel circuits. electrical wiring may additionally maintain damage from fire injuries, rendering important components essential for activation inoperable. gadget screw ups also can be due to mechanical problems which include put on and tear, corrosion, or incorrect set up. Even the most state-of-the-art computerized manipulate systems and detecting technologies may lose their effectiveness in such situations. The complete aim of the suppression device is compromised whilst electrical failure prevents CO_2 from being released, that may result in out-of-control fire unfold, system damage, and employee risk.

4. Objective

State-of-the-art CO2 hearth suppression systems use carbon dioxide to extinguish fires by means of displacing oxygen in the covered vicinity. those structures are designed to reduce oxygen levels to suppress combustion, with CO2 being calmly distributed for the duration of the enclosure in seconds. As a certainly happening fuel, CO2 has minimal impact at the greenhouse effect and does no longer expend the ozone layer. a number of the advantages encompass:

1. Automatic Fire Detection and Suppression
2. Protection of Critical Assets
3. Minimize Downtime and Recovery Efforts
4. Adaptability and Scalability
5. Enhanced Safety for Personnel and Equipment
6. Environmental Considerations
7. Cost-Effectiveness and Long-Term Value

A complete CO2 flooding gadget is an energetic hearth suppression machine that robotically turns on whilst heat or smoke detectors are brought about, presenting widespread advantages over handheld extinguishers, which require guide operation. even as putting in and keeping such systems in smaller enclosures may be steeply-priced, the funding is precious for the smooth and reliable firefighting capabilities they provide, making them extensively used in production and commercial environments.

5. Potential Hazards

The CO_2 fireplace suppression gadget within the documentation cell poses dangers due to the fireplace load from timber furniture, paper, and electronics, growing fireplace unfold. CO_2 displacement creates asphyxiation hazards, especially with best one goes out. extra risks encompass smoke inhalation, CO_2 leakage thru unsealed gaps, and thermal surprise to electronics, probably negative servers and touchy device. Fire Hazards (Class-A & Class-C)

1. Oxygen Displacement & Asphyxiation Risk
2. Entrapment Hazard
3. Smoke Inhalation & Toxic Gas Exposure
4. CO_2 Leakage and Seepage Risks
5. Thermal Shock to Electronic Equipment

6. Research Methodology

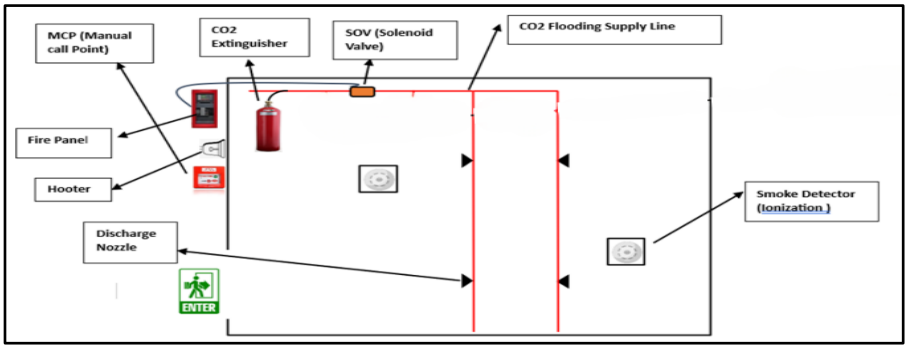

Fig.2: System Layout.

1. System Layout: Smooth agent flooding systems require sufficient cylinders, such as a reserve financial institution, for fuel supply. Cylinders need to be securely installed for clean inspection, with strain gauges and remote tracking. Distribution piping connects to discharge manifolds, ensuring reliable operation. Proper

enclosure and protection from mechanical or environmental damage are vital to prevent system failure and ensure safety during maintenance or activation.

2. Cylinder Valves: Cylinder valves need to have pneumatic actuators and be monitored with stress gauges. The pilot cylinder controls pressure release to open slave cylinders, ensuring easy operation. Automatic closure occurs when strain drops, maintaining cylinder integrity and preventing corrosion. Flexible high-pressure hoses connect the cylinders, and check valves ensure safety during maintenance by preventing agent loss.

3. Pressure Monitoring: Pressure tracking is available locally via cylinder gauges and remotely using supervisory pressure switches. These switches signal a drop in pressure (around 2200 PSI) to alert for potential issues, ensuring the system operates efficiently and any pressure drops are promptly addressed for equipment reliability.

4. **Distribution Pipe Network and Nozzles**: The distribution pipe network must be carefully designed to ensure uniform delivery of the clean agent. Pipe placement and nozzle installation should comply with municipal standards and safety codes, including the ASME B31.1 Power Piping Code and NFPA 2001, to guarantee optimal performance and consistent agent flow throughout the protected area.

5. Release Modes - Automatic: The automatic release mode uses advanced smoke detection technology to trigger fire suppression without human intervention. Smoke detectors signal the control panel, which activates a solenoid valve to release CO_2 gas. The gas displaces oxygen, suppressing the fire and preventing re-ignition. This quick and precise mechanism ensures efficient fire suppression with minimal delay.

6. **Release Modes - Manual (MCP)**: The manual call point (MCP) allows personnel to activate the fire suppression system in emergencies. The MCP signals the control panel to release CO_2 gas, which flows through pipes to discharge nozzles, reducing oxygen levels to extinguish the fire. This manual method ensures control when automatic systems are unavailable or human intervention is necessary.

7. New Implementation in Old Setup

7.1 Bypass Valve

The pass valve ensures persevered fireplace suppression if the main machine fails. it is able to manually launch CO2 gas into the piping gadget, bypassing automatic controls. placed in secure, on hand locations, it guarantees effective hearth suppression even in the course of strength loss or gadget malfunctions. ordinary renovation and operator education are essential for secure, effective operation in emergencies.

A mechanical, manual release component utilized in CO2 hearth suppression structures is known as a skip valve. without the need for automatic or digital controls, it serves as a failsafe system that allows the direct release of CO_2 gasoline from the storage cylinders into the distribution piping.

This valve is important while important gadget parts, together with control panels, manual call factors (MCPs), or solenoid valves, prevent operating due to environmental elements, electric failure, or harm.

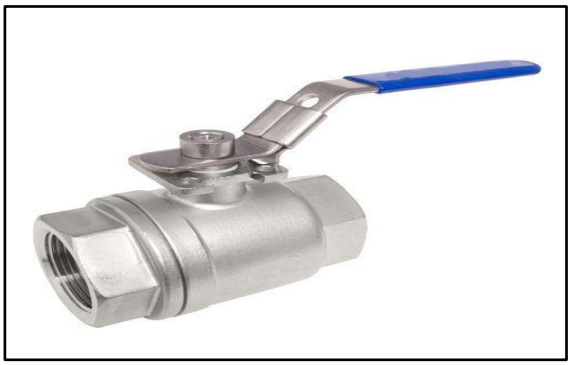

Fig.3: BYPASS Valve [9].

7.2 Working

With out using automated triggers or electric signals, a CO_2 hearth suppression machine's skip valve may be physically opened via an operator. when it's far became on, it offers high-stress CO_2 gasoline from the garage cylinders a direct path through the distribution piping and out into the protected vicinity through nozzles which can be positioned strategically. so that it will effectively suppress the fire and make sure uniform gas distribution for complete chance coverage, the emitted CO_2 speedy displaces oxygen, decreasing its concentration beneath combustion stages. Importantly, the pass valve gives a dependable failsafe in emergency situations by way of overriding the whole manipulate machine, together with detectors, control panels, MCPs, and solenoid valves. It does this independently and maintains to operate irrespective of the event of electrical or system failures.

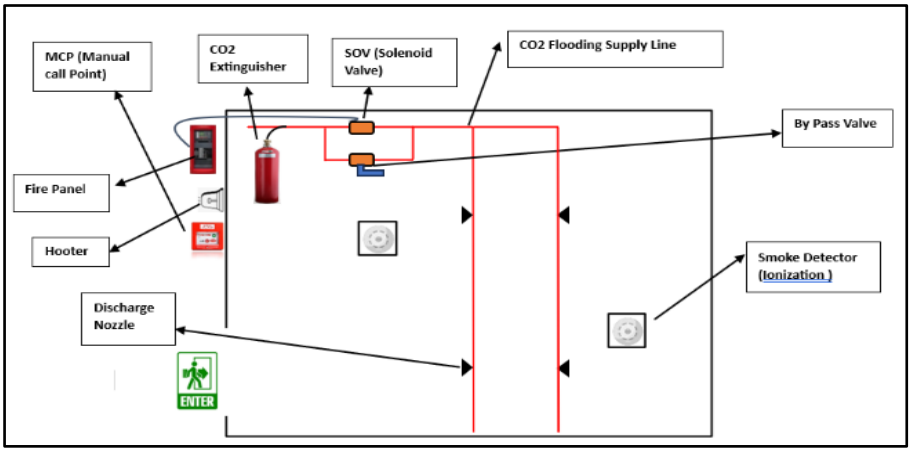

Fig.4: System Layout with Addition Of BYPASS Valve

7.3 Best Practices for Bypass Valve Use

With a view to guarantee secure manual activation all through crises, CO_2 fireplace suppression gadgets are strategically placed in a non-unsafe, without problems on hand vicinity outside the blanketed location. To avoid abuse or mishaps, the valve should simplest be operated through authorized and nicely skilled individuals. To ensure that the valve, piping, and all associated elements retain to operate at their great, ordinary protection and inspections are important. To assist operators in emergency situations, the bypass valve should even have a clear label and clear, easy-to-read operating commands displayed nearby.

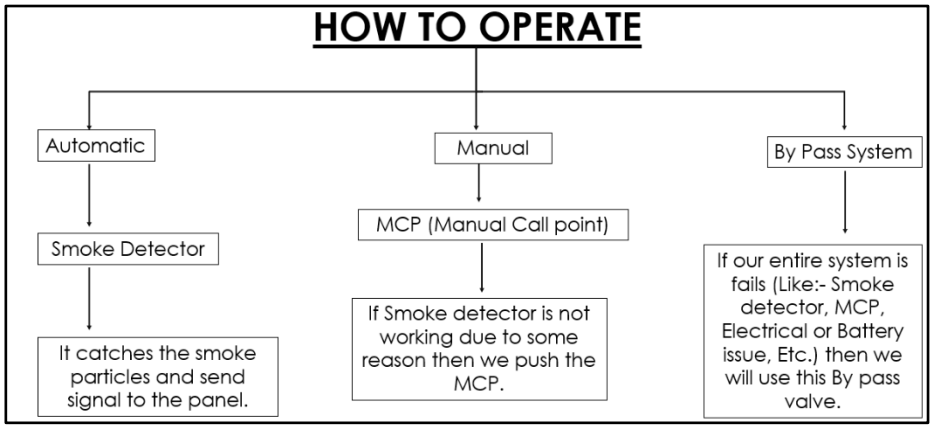

Fig.5: Operation of System

8. Result

The implementation of a routinely operated pass valve inside the CO_2 fireplace suppression gadget significantly complements the machine's reliability and operational protection. This valve features as a guide override, designed to discharge CO_2 gas directly from the garage cylinders to the distribution nozzles within the occasion of a system failure, inclusive of a power outage, manipulate panel malfunction, or actuator fault. all through trying out beneath simulated emergency situations, the bypass valve efficaciously activated and enabled uninterrupted CO_2 discharge, bypassing the complete electronic and automatic manipulate collection. This guide operation ensures that fire suppression can still occur even when the main gadget is inoperable, thereby imparting a important fail-secure mechanism.

The mixing of the pass valve introduces numerous key benefits. It improves system redundancy, allowing guide activation when computerized controls are compromised. that is especially useful in high-threat environments in which system failure should bring about catastrophic loss. The valve operates independently of electrical strength, making it surprisingly dependable in the course of strength outages or digital machine faults. It additionally aligns with exceptional practices and international standards, inclusive of NFPA 12, which advise redundancy in fireplace protection systems for crucial infrastructure. additionally, this selection may be retrofitted into existing systems, making it a value-powerful upgrade to enhance safety and compliance. normal, the skip valve ensures continuous hearth protection functionality, reduces the chance of system failure during emergencies, and notably increases the resilience and reliability of CO_2 fire suppression structures.

9. Conclusion

Via permitting manual activation inside the event of a gadget failure, the incorporation of a mechanical bypass valve improves the dependability and safety of CO_2 fireplace suppression structures. It gives an low priced, retrofittable answer that improves device redundancy and operational resilience while ensuring non-stop fireplace protection in dire instances, inclusive of strength outages.

10. Future Scope

Improving resilience, dependability, and intelligence mainly in essential infrastructure can be the primary dreams of CO_2 fireplace suppression structures inside the future. powerful backup answers are crucial given the growing reliance on electronic manipulate structures. future traits may comprise sensors and IoT-primarily based clever monitoring technologies for predictive renovation and real-time diagnostics, recognizing viable troubles before they have an effect on machine operation. Pneumatic, mechanical, and electrical components used in hybrid activation systems might also provide easy operation within the occasion of a breakdown. skip valves and different parts will be more durable thanks to material advancements, while semi-automatic guide overrides may cast off the requirement for external energy sources. For expanded safety, regulatory improvements might also need replica systems. moreover, experimental studies and modeling techniques will improve device overall performance below various failure eventualities. those developments will bring about CO_2 fireplace suppression systems which might be greater clever and reliable, ensuring ongoing safety even in hard situations.

Acknowledgement

The authors would like to express their sincere gratitude to Dr. Premanand S. Chauhan, Vice Chancellor, Vikrant University, Gwalior for their invaluable support, encouragement, and guidance throughout the course of this research. Their vision and commitment to promoting sustainability in academic institutions have served as a profound source of inspiration. Their continuous support played a pivotal role in the successful completion of this research work.

Conflict of Interest

The authors declare that there is no conflict of interest related to this research work.

Source of Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Guo, J., Gao, B., Liu, Y., Chen, C., Cai, G., Wang, L. (2024). Research and Application of CO_2 Fire Prevention Mechanism and Key Technologies in Mines: A Review. *Fire*, *7*(10), 353. https://doi.org/10.3390/fire7100353

[2] Gaidukova, O., Misyura, S., Donskoy, I., Morozov, V., Volkov, R. (2022). Pool Fire Suppression Using CO_2 Hydrate. *Energies*, *15*(24), 9585. https://doi.org/10.3390/en15249585

[3] Shukla, K., Tiwary, A., Yadav, A., et al. (2021). An Innovative Designing of a Clean Agent Flooding System for Server Room of an Educational Institute. *IJARSCT*, 7(2), 433-439.

[4] Dinesha, A., Bensonb, C. M., Holbornb, P. G., Sampatha, S., Xiong, Y. (2020). Performance evaluation of nitrogen for fire safety application in aircraft. *Reliability Engineering & System Safety*, 202, 107044, https://doi.org/10.1016/j.ress.2020.107044.

[5] Tang, L., Qi, Y., Li, X., Wang, J. (2019). Coal fire prevention in large areas over long term with a composite inert gas—a case study in Tangkou coal mine, China. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *46*(1), 1060–1070. https://doi.org/10.1080/15567036.2019.1684600

[6] Su, J. Z., Kim, A. K., Crampton, G. P., Liu, Z. (2001). Fire Suppression with Inert Gas Agents. *Journal of Fire Protection Engineering*, 11(2):72-87. doi:10.1106/X21V-YQKU-PMKP-XGTP

[7] Prakash, N. S. (2017). *Manual of Fire Safety*, 1st Edition, New Delhi, CBS Publishers, ISBN 978-9389396669.

[8] https://law.resource.org/pub/in/bis/S03/is.15528.2004.pdf

[9] https://5.imimg.com/data5/MS/GK/MY-2750929/manual-operated-ball-valve.jpg.

[10] https://5.imimg.com/data5/SELLER/Default/2024/10/459083809/DX/ZZ/CN/2334408/co2-flooding-system-500x500.png