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Application of Pressure-Sensitive Gas Fuses for Automatic Flow Cutoff in Earthquake-Induced Pipeline Damages

Authors:

Seyed Saeed Beheshti[1, *], Mohammad Safi[1], Amir Hossein Omranpour[1], Fazel Nejabati[1]

Abstract

With the development of natural gas distribution networks in over 80% of urban and rural areas of Iran and considering the country's location in the seismically active Alp-Himalaya belt, the country's lifeline infrastructure, especially gas infrastructure, is vulnerable to earthquake-induced damage. Gas leaks and post-earthquake fires are among the very critical secondary hazards and pose serious threats to public safety and infrastructure resilience. In this context, gas fuses—functionally equivalent to Excess Flow Valves (EFVs)—are introduced as passive and pressure-sensitive safety mechanisms designed to automatically shut off the gas flow in case of a pipe failure or leak. This study evaluates the operational performance and applicability of such fuses in the Iranian gas distribution network. To conduct this evaluation, a dedicated testing platform was created to simulate normal conditions and incidents in scenarios that include normal consumption, limited leaks, and complete pipe failures. The tests were designed to assess the fuse's response to sudden pressure drops, the fuse's ability to detect abnormal and critical flow conditions, and its ability to automatically restore gas flow after system stabilization. This reversible capability allows the fuse to resume service after the failure has been resolved without manual intervention. The findings indicate that gas flow fuses operate as a completely passive system, requiring no external energy source, and also provide the capability to restore gas flow after a fault. This preliminary study confirms the feasibility of using gas fuses (EFVs) as a practical solution to enhance the seismic resilience of gas distribution systems.

Keywords: Excess Flow Valve (EFV), Earthquake, Gas Distribution Network, Automatic Shutoff, Gas Fuse

1. Faculty of Civil, Water, and Environmental Engineering, Shahid Beheshti University, Tehran 1983969411, Iran

[*] Corresponding author. E-mail: s_beheshti@sbu.ac.ir

1. Introduction

With the rapid expansion of urban and rural gas distribution networks in Iran, ensuring the security of this vital infrastructure against natural disasters—especially earthquakes—has become a major concern in crisis management and urban planning. Global experience shows that one of the deadly secondary effects of earthquakes is the failure or leakage of gas pipelines, which leads to explosions and fires in densely populated areas. Recent numerical simulations of local gas distribution networks have shown that in densely populated residential areas, permanent ground changes or earthquake-induced damage to joints and branch connections can quickly lead to gas leaks and consequently to ignition and fires (Zhu et al., 2022). These findings underscore the critical importance of proactive gas flow control in urban environments.

Analysis of past urban gas incidents has shown that a significant portion of earthquake-related damage is due to delays in shutting off the gas supply. Current safety systems are often controlled manually or electrically. However, post-earthquake conditions often involve power outages, blocked access routes, and critical disruptions that make human intervention difficult. In such conditions, even a short delay can turn into uncontrollable fires or explosions. Therefore, there is an undeniable need for a passive rapid response system—independent of electricity and operator intervention—that can automatically shut off the gas flow in response to sudden leaks or abnormal pressure drops (Li et al., 2021).

In Iran, within the framework of the project "Vulnerability Studies and Strengthening the Security of the Tehran Province Gas Network Against Earthquakes," conducted in 2003 in collaboration with the University of Water and Power Industry (Shahid Abbaspour) and the Osaka Gas Company of Japan, the evaluation of gas shut-off valves as a safety mechanism based on pressure drop detection in urban gas systems was proposed. This initiative aimed to evaluate the ability of such fuses to cut off gas flow under abnormal conditions and automatically restore it after stabilization, and it was included in the project stakeholders' action plan.

In this study, the performance of a gas shut-off fuse designed to respond to pressure drops in simulated critical conditions is evaluated using a laboratory-scale device developed by researchers. The analysis focuses on evaluating the performance of these fuses for leak detection, rapid gas flow cessation, and restoration after system stabilization. The main objective of this research is to evaluate the feasibility of using a passive and energy-independent safety component as an effective measure to enhance the seismic resilience of urban gas distribution networks.

2. Literature Review

In recent decades, with the increase in urban density and the expansion of urban gas networks, the seismic vulnerability of urban areas in this field of urban services has similarly increased. Researchers have focused on developing rapid response systems to detect gas leaks and prevent explosions after earthquakes. One of the main objectives of this research has been the development of equipment and algorithms capable of detecting abnormal flow conditions and automatically shutting off gas or other energy-carrying fluids. These systems often operate based on principles similar to pressure-sensitive mechanisms, such as excess flow valves (EFVs).

In an experimental study, a completely mechanical gas shut-off fuse that works without any external energy source was designed and analyzed. This device includes a pressure-sensitive sliding element that, when exposed to an excessive flow beyond the threshold, compresses a central spring and moves to a closed position, blocking the gas flow. Using FSI (fluid-structure Interaction) simulations and laboratory-scale tests, they confirmed a response time of less than 0.3 seconds and complete closure under variable flow conditions (Lee et al., 2021).

In another study, a dual protective system that used a seismic sensor and a pressure transducer to detect seismic movement and sudden pressure drops was developed. The system included a logic controller and a solenoid valve that would automatically activate in the event of detecting abnormal conditions. Designed for immediate response without human intervention, the device successfully cut off power and gas in less than five seconds (Rahnam Sohan et al., 2022; Mamdoohi et al., 2013).

An intelligent gas leak detection system using an MQ3 semiconductor sensor, a microcontroller, and a solenoid valve connected to a relay was designed. When detecting a flammable gas concentration above a threshold, the system issued an audio-visual alarm, displayed the leak status on an LCD screen, and cut off the gas flow through a solenoid. Experimental tests showed detection and shutdown response times between 2 and 3 seconds under controlled leak conditions (Harry et al., 2024).

In another study, a fuzzy logic-based control algorithm dedicated to regulating gas consumption was developed (e.g., Ahadi et al., 2018; Mahpour et al., 2022). The system received inputs such as pressure, flow rate, and consumption rate, and based on fuzzy inference rules, determined whether to maintain, reduce, or cut off the gas flow. Simulations in MATLAB showed that the system was effective in identifying irregular behaviors and responding appropriately under fluctuating conditions (Dayev, 2024).

In a technical paper, a mechanical relief valve used in automotive lubrication systems was introduced. This valve operated using a pressure-sensitive piston that, when exposed to a pressure differential above a specified threshold, compressed a spring and redirected the flow to a bypass line. Although this device is designed for fluid systems, its mechanical logic aligns with the operational principles of EFVs (Nugent, 1968).

Another engineering study evaluated the performance of a mechanical spring valve designed to respond to sudden pressure drops. This device included a pressure diaphragm and a piston with a spring that remained open under normal flow conditions. In the event of a rapid pressure drop, the spring closes the valve to stop the flow. Although this mechanism was not specifically developed for gas distribution systems, its passive and pressure-sensitive behavior is consistent with the concepts of EFV (Coskun & Pehlivan, 2021).

Despite extensive efforts to design flow control systems, most existing studies have focused on sectors other than the infrastructure of urban yard arteries, such as automotive applications or turbines, or are heavily dependent on an external factor like electronic power and energy sources. To date, the performance of a completely passive, mechanical, resettable, and energy-independent flow cutoff system for automatic gas flow interruption in emergency conditions in residential gas networks has not been comprehensively studied. Therefore, this research addresses this gap by experimentally evaluating the performance of a gas shut-off fuse under simulated seismic scenarios in urban gas distribution systems.

3. Methodology

In this section, the data collection procedure and the gathered information are described. Moreover, the experimental setup and the method used in this study are explained.

3.1. EFV Operation Mechanism and Test Apparatus Configuration

The operation of the excess flow valve (EFV) is based on the principle of automatically interrupting the gas flow when the volumetric flow rate exceeds a predetermined threshold. This threshold corresponds to the maximum flow rate expected under normal consumption conditions. If a sudden surge in flow occurs—typically resulting from a downstream pipe rupture due to seismic activity or mechanical failure—the EFV is triggered and closes, thereby immediately stopping the gas supply to prevent potential hazards such as explosion or fire.

Following the closure, if the pressure between the upstream and downstream sides of the valve gradually equalizes (indicating that the leak or rupture has been resolved or isolated), the valve automatically resets and allows gas flow to resume. This passive mechanism, which requires no external energy, renders the EFV particularly suitable for earthquake-prone gas distribution networks, where secondary hazards are a major safety concern.

To conduct the experiments, a custom-made test apparatus was designed and fabricated. The main components of the system include a set of control valves and excess flow valves (EFVs), two flow meters with maximum capacities of 40 m^3/h and 60 m^3/h, and two pressure gauges with upper limits of 100 psi and 2 psi. The apparatus also contains a leakage measurement assembly composed of aluminum and plastic tubes, along with a graduated cylinder. A compressor is used to supply the required pressure and flow rate during the tests. In addition, four EFVs with flow capacities of 1.6 m^3/h, 2.5 m^3/h, 4 m^3/h, and 6 m^3/h were installed in the system for performance evaluation. Figure 1 provides an overview of the developed experimental apparatus.

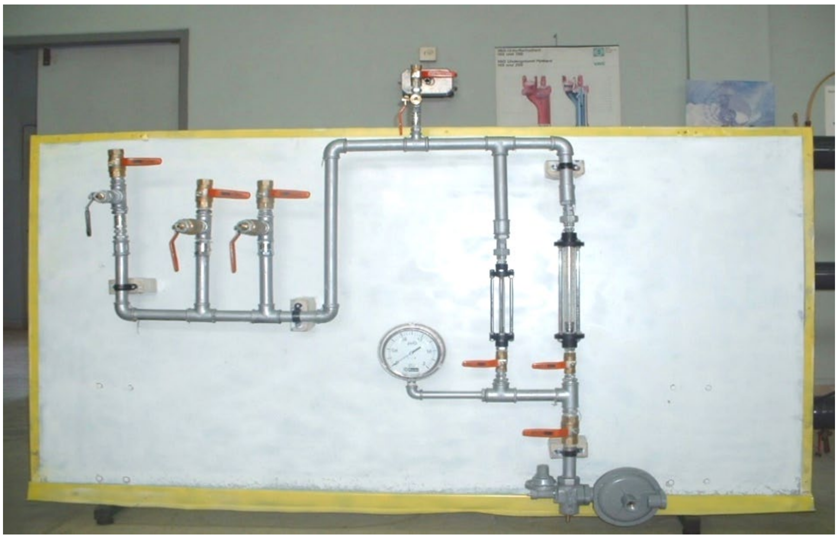

Figure 1. View of the fabricated apparatus for gas fuse testing

3.2. Operating Procedure of the Test Apparatus

The experimental procedure starts with compressed air supplied by a compressor. This air first passes through a pressure regulator, where both the pressure and flow rate are adjusted according to the specific needs of the test. The regulated airflow is then directed through one of two flow meters, chosen based on the expected flow capacity of the excess flow valve (EFV) being tested.

After measurement, the airflow enters the selected EFV. Each EFV is connected to a separate outlet line, allowing its performance to be evaluated independently.

Downstream of each EFV, two control valves are installed. The first valve simulates normal consumption conditions by maintaining the nominal flow rate (VN[1]) and is also used later for leakage measurement. The second valve is used to create a sudden, high-flow condition—similar to what might happen if the downstream pipeline were to rupture. This setup makes it possible to assess how the EFV behaves under both standard operating conditions and emergency scenarios.

[1] Nominal Flow Rate

3.3. EFV Function and Leakage Measurement Procedure

The excess flow valves (EFVs) used in this study are designed to automatically shut off the gas flow when the flow rate exceeds a predefined threshold. This excessive flow can result either from unusually high gas consumption or from a rupture in the downstream pipeline.

To restore the gas flow, the pressure on both the upstream and downstream sides of the EFV must become equal. In other words, after the valve has been triggered, the downstream issue—whether due to overconsumption or a pipe break—must be resolved. The small amount of leakage permitted by the EFV allows the pressure to gradually equalize, which eventually leads to the valve reopening automatically.

To replicate this behavior during testing, a control valve is placed immediately downstream of the EFV. Closing this valve causes the pressure to equalize within a few seconds, enabling the EFV to reset and resume gas flow.

For measuring leakage, the outlet valve is connected to a flexible hose that leads to a graduated cylinder. The leakage flow is directed beneath the cylinder using a metal connector, and the resulting drop in the water level inside the cylinder is used to determine the leakage rate. Figures 2 and 3 illustrate the experimental setup and the leakage measurement system.

Figure 2. The EFV testing setup integrated with the leakage measurement unit

Figure 3. EFV mounted with a transparent plexiglass pipe for monitoring flow cut-off behavior

4. Experimental Evaluation of EFV Performance under Various Flow Conditions

The experimental scenarios described in this study are deliberately designed to reflect the most common types of damage observed in urban gas distribution systems following earthquakes. Earthquake-induced damages typically fall into several major categories: (1) full rupture of service pipes due to intense ground shaking or permanent ground deformation, (2) partial disconnection or joint loosening at threaded or mechanical connections—especially in older infrastructures, (3) pressure regulator malfunction or overload caused by rapid pressure fluctuations, and (4) residual microleakages due to material fatigue or undetected cracks. Each scenario tested in this study corresponds to one or more of these real-world conditions.

The first scenario starts with a normal gas flow and then introduces a sudden increase in flow rate. This setup is meant to simulate what happens when a service pipe suddenly breaks— an event commonly reported during seismic events due to pipe-soil interaction or unanchored service connections. The second scenario, focused on leakage measurement after EFV activation, replicates the case of partially compromised connections or microfractures that result in slow but dangerous gas leakage—conditions often linked to aging infrastructure and cumulative stress. The third scenario, high-pressure testing, models a system response under regulator failure or overpressure situations, which are frequently reported after earthquakes due to system depressurization or upstream valve failures.

By designing the laboratory tests to match actual damage patterns observed in seismic assessments of cities such as Tehran, this study offers a practical and technically sound perspective on how EFVs perform in realistic scenarios. These test conditions are intentionally selected to go beyond idealized laboratory environments and better represent the unpredictable and dynamic behavior of gas networks following an earthquake.

To systematically evaluate how excess flow valves (EFVs) respond to real-world conditions, three distinct test scenarios were developed. These include steady-state flow with sudden rupture simulation, post-activation leakage analysis, and performance assessment under elevated pressure. Detailed procedures and corresponding findings for each scenario are presented in Sections 4.1 through 4.3.

4.1. Shut-off Flow Rate Test at 0.25 psi and Flow Regulation Based on EFV Label Specifications

In this first test, we tried to recreate what happens when a gas pipe suddenly breaks—something that often occurs during an earthquake. This kind of break causes the gas flow to increase sharply. To simulate this, we used compressed air, passed it through a pressure regulator, and then sent it into the EFVs. Because the valves had different flow capacities, two flow meters with different ranges were used to properly measure and control the flow. By adjusting the valves placed after the EFVs, we could create both normal flow and sudden high-flow situations to see how the valves would react.

Although the pressure was intended to remain steady at 0.25 psi, small fluctuations were consistently recorded, ranging from about 0.2 to 0.55 psi. These variations were mostly due to minor inconsistencies in the regulator's performance and slight instability in the airflow supply.

To make sure the findings were reliable and reproducible, the test was repeated roughly 170 times for each type of EFV. The full breakdown of measured values and technical analysis for this scenario is presented in Section 5.1.

4.2. Gas Leakage Measurement Test After Flow Shut-off

In this part of the experiment, we checked how much gas might still leak through the EFV after it had shut off the flow. To create this condition, we used a control valve installed downstream of the EFV to simulate low-consumption situations. This setup helped the EFV stay in its closed position, making it possible to measure the small amount of gas that could still pass through—similar to what might happen in real-life gas pipelines after damage.

To measure the leakage, we used a simple and effective method. A flexible hose was connected to the outlet of the EFV, and the other end of the hose was placed into a container of water. As gas leaked through the closed valve, it traveled through the hose and formed bubbles in the water. We then positioned a graduated cylinder upside down in the water to collect the gas bubbles. The rising gas displaced the water in the cylinder, and this allowed us to measure the amount of leaked gas by tracking the volume of water pushed out over time.

This approach made it easy to see and record even very small leaks. Each EFV model was tested one by one using this setup, so we could compare how much gas leaked from each type. The same conditions were kept for all tests to ensure the results could be fairly compared.

The complete results and interpretation of this leakage test are provided in Section 5.2.

4.3. Performance Evaluation of Excess Flow Valves Under Elevated Pressure Conditions

This part of the study covers the third test scenario introduced earlier in Section 4, focusing on how EFVs behave when exposed to high gas pressure. The same shut-off and leakage tests described in Sections 4.1 and 4.2 were repeated here, but under elevated pressure, to see if the valves still worked the same and whether they could reopen after shutting off.

Two common installation setups were used to reflect real conditions. In the first setup, the EFV was installed without any pressure regulator downstream. Compressed gas was slowly added, and the flow was increased past the valve's rated capacity. This helped us check how the valve shuts off the flow when pressure isn't controlled.

In the second setup, the EFV was placed before a pressure regulator, and the inlet pressure was kept at 80 psi. The regulator helped stabilize flow on the downstream side, so we could watch how the pressure difference on both sides of the valve affected its behavior when flow started.

All EFV models were tested under both setups to make sure results were consistent and comparable, and so we could study the effect of pressure in a fair way. The complete results and performance analysis under these elevated pressure conditions are presented in the next Section.

Technical Notes and Recommended Measures for Downstream Pressure Conditions:

Based on the performance charts in the manufacturer's catalog (see Figure 4), excess flow valves (EFVs) are designed to work reliably at a minimum pressure of 35 millibars. But in our experiments, the pressure measured right after the regulator—just downstream of the EFV—was only about 17.5 millibars. That's noticeably lower than the recommended level, which means the conditions during testing were quite different from what the valve was originally designed and tested for. Because of this low pressure, there's a real chance that the EFVs might not work as expected—especially when it comes to automatically restoring the gas flow after it's been shut off.

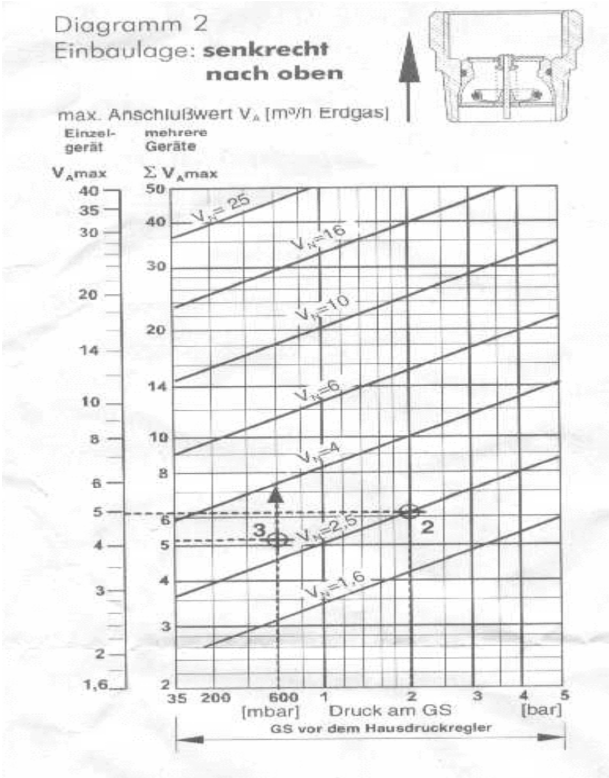

Figure 4. Performance Charts from the Manufacturer Catalog for EFV Operation

To address this issue and enable the re-establishment of gas flow after EFV activation in low-pressure systems, the following two configurations are proposed:

1. Install a shut-off valve at a short distance downstream of the EFV: This arrangement allows for direct manual control of the downstream pressure, facilitating pressure equalization across the valve.
2. Install two valves upstream of the EFV: One valve serves as the main shut-off control, while the second is used to purge the residual gas trapped between the EFV and the shut-off valve. This setup helps reduce the pressure differential across the EFV, thereby enabling the valve to reopen and restore flow.

5. Results

The results of these studies indicate that all excess flow valves (EFVs) provided flow rates at 0.25 psi that matched their labeled nominal capacities, and in most cases, flow cessation occurred when the flow rate was approximately 70% higher than the nominal value. Among the tested excess flow valves, the 1.6 cubic meter per hour model showed a reduction in leakage after repeated tests and was able to resume gas flow after a delay. The 2.5 cubic meter per hour model performed similarly to the samples but with significant improvements in leak control and reliable self-regulating capabilities, making it the most effective sample among those tested. In contrast, the 4 cubic meter per hour model showed no measurable leakage but did not restore flow to the circuit after the flow was interrupted. The 6 cubic meter per hour model exhibited erratic leakage behavior and did not succeed in resuming flow after being shut off in any instance.

To present the findings in a more structured and accurate manner, the results have been categorized based on the three experimental scenarios defined in the previous section. In the following subsections, the outcomes of each scenario are analyzed and reported separately.

5.1. Shut-off Flow Results Under Simulated Pipe Rupture Conditions

In this test, we gradually increased the gas flow rate at a pressure close to 0.25 psi to see how each EFV model would react. The expectation was that the valves would shut off automatically once the flow went well beyond their nominal capacity. As the results showed, all the tested valves reliably stopped the flow when it reached about 69% to 72% higher than their labeled rating.

Tables 1 to 4 show the minimum, maximum, and average flow rates and activation pressures recorded for the four EFV models—1.6, 2.5, 4, and 6 m³/h. Each model was tested around 170 times to make sure the data was consistent and reliable.

Table 1. Experimental Results of the 1.6 m³/h Excess Flow Valve (EFV)

EFV Series	Excess Flow for Shut-off (%)	Flow Rate			Pressure			No. of Repetitions
		Min (m³/h)	Max (m³/h)	Avg (m³/h)	Min (psi)	Max (psi)	Avg (psi)	
First Series EFV	72%	2.17	2.21	2.20	0.25	0.55	0.40	156
Second Series EFV	72%	2.17	2.21	2.20	0.25	0.55	0.40	156

Table 2. Test Results for 2.5 m³/h EFV

EFV Series	Excess Flow for Shut-off (%)	Flow Rate			Pressure			No. of Repetitions
		Min (m³/h)	Max (m³/h)	Avg (m³/h)	Min (psi)	Max (psi)	Avg (psi)	
First Series EFV	69%	3.47	3.87	3.63	0.25	0.55	0.40	156
Second Series EFV	69%	3.47	3.87	3.63	0.25	0.55	0.40	156

Table 3. Test Results for 4 m³/h EFV

EFV Series	Excess Flow for Shut-off (%)	Flow Rate			Pressure			No. of Repetitions
		Min (m³/h)	Max (m³/h)	Avg (m³/h)	Min (psi)	Max (psi)	Avg (psi)	
First Series EFV	69%	5.60	5.84	5.82	0.25	0.55	0.40	156
Second Series EFV	69%	5.60	5.84	5.82	0.25	0.55	0.40	156

Table 4. Test Results for 6 m³/h EFV

EFV Series	Excess Flow for Shut-off (%)	Flow Rate			Pressure			No. of Repetitions
		Min (m³/h)	Max (m³/h)	Avg (m³/h)	Min (psi)	Max (psi)	Avg (psi)	
First Series EFV	69%	8.46	9.06	8.72	0.25	0.55	0.40	156
Second Series EFV	69%	8.46	9.06	8.72	0.25	0.55	0.40	156

Figure 5 illustrates the average flow rate at which each valve is activated. The values—2.21, 3.87, 5.84, and 9.06 m³/h—correspond to the tested models in the same order and were based on repeated test cycles.

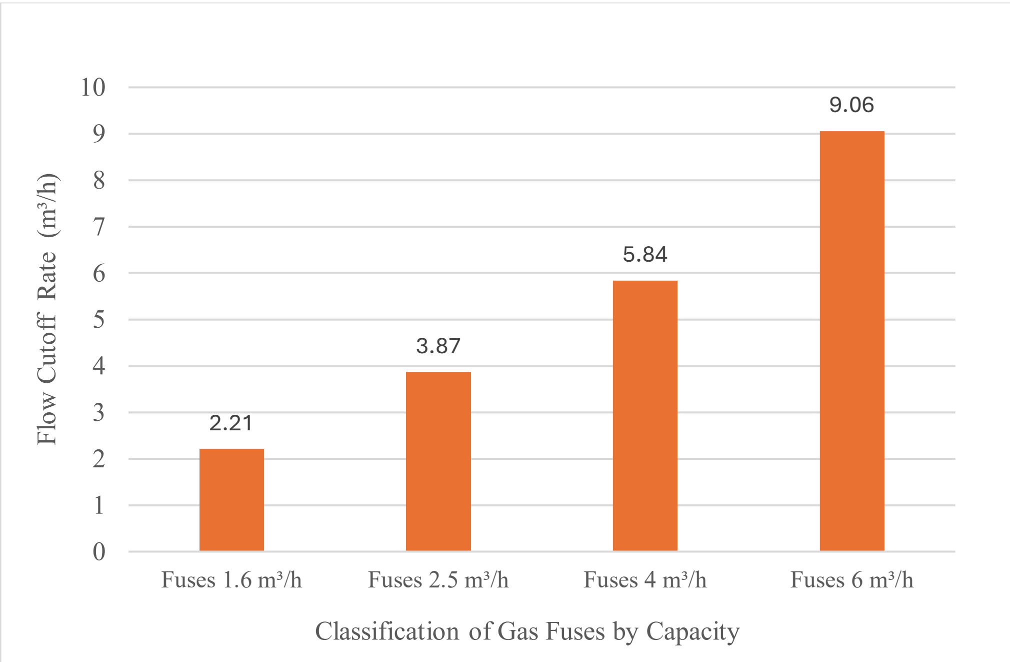

Figure 5. Comparison of Maximum Flow Cutoff Rates in Different Fuses at 0.25 psi Pressure

These measured values show that, on average, each EFV triggered well above its nominal flow capacity, highlighting their built-in tolerance for short-term surges. This means the results reflect how the valves really behave in a controlled setting—not just what their labels say.

When looking at the data trend, a clear pattern appears: the higher the nominal capacity of the valve, the higher the flow rate needed to shut it off. This trend, also seen in Tables 1–4 and Figure 5, shows that the valves are designed in a way that lets them allows extra flow just before activation. From a safety perspective, this kind of behavior gives important clues about how EFVs would work in real-world emergencies like earthquakes.

Figure 6 presents a combined chart showing both the maximum cutoff flow rates and the peak activation pressures for all four EFV models. This dual-parameter view helps compare the flow and pressure behavior of each valve in one visual.

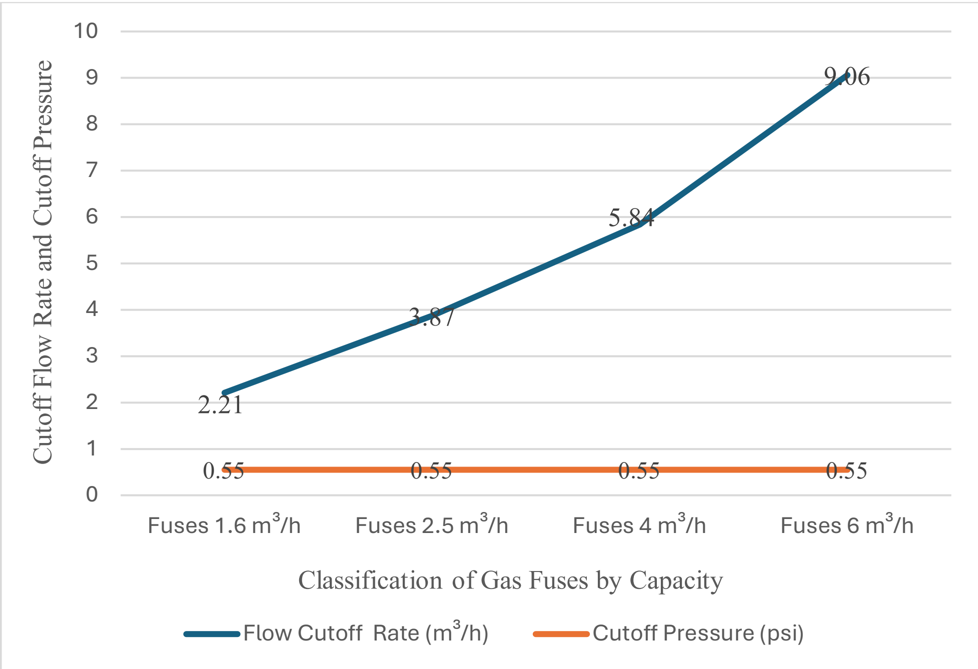

Figure 6. Correlation Between Maximum Flow Rate and Maximum Cutoff Pressure in Different Fuses

As seen in the figure, the cutoff flow rate increases with valve capacity, ranging from 2.21 to 9.06 m^3/h. In contrast, the activation pressure remains constant at 0.55 psi across all models. This indicates that while the flow response depends on the mechanical structure of each valve, the pressure threshold is fixed and independent of capacity.

This consistent pressure behavior confirms the valves are engineered to react reliably to pressure surges regardless of their size. Together with the variation in cutoff flow, this reinforces the reliability and mechanical integrity of these EFVs under sudden flow increase conditions—especially during low-pressure disturbances such as seismic events.

Overall, the results confirm that EFVs can respond effectively to sudden flow surges caused by pipe ruptures, which makes them a strong option for improving gas network safety in seismic zones.

5.2. Leakage Performance After Shut-off

The leakage tests provided important insights into how well each Excess Flow Valve (EFV) model limited gas flow once the valve had shut off. As shown in Tables 5 through 8, each model was tested multiple times under the same conditions. The results revealed noticeable differences in leakage behavior among the valves.

Table 5. Measured Leakage Values across Repeated Tests for the 1.6 m³/h Excess Flow Valve

Test No.	1	2	3	4	78	79	80	81	153	154	155	156
First Series EFV	-	-	-	-	0.26	0.26	0.17	0.15	0	0.12	0.146	0.09
Second Series EFV	1.8	0.226	0.124	0.166	0.22	0.18	0.13	0.09	0.09	0.16	0.13	0.1

Table 6. Measured Leakage Values across Repeated Tests for the 2.5 m³/h Excess Flow Valve

Test No.	1	2	3	4	78	79	80	81	153	154	155	156
First Series EFV	-	-	-	-	1.645	1.323	1.287	1.148	1.17	2.546	1.02	1.07
Second Series EFV	0.247	0.122	0.202	0.16	0.091	0.241	0.243	0.219	0.427	0.143	0.262	0.333

Table 7. Measured Leakage Values across Repeated Tests for the 4 m³/h Excess Flow Valve

Test No.	1	2	3	4	78	79	80	81	153	154	155
First Series EFV	-	-	-	-	0	0	0	0	0	0	0
Second Series EFV	0.179	0.0685	0.148	0.0867	0.0592	0.0574	0.061	0	0	0	0

Table 8. Measured Leakage Values across Repeated Tests for the 6 m³/h Excess Flow Valve

Test No.	1	2	3	4	78	79	80	81	153	154	155	156
First Series EFV	-	0	0	0	0	0	0	0	0	0	0	0
Second Series EFV	-	2	1.9369	1.037	0	0.0326	0.0484	0.171	0	0	0	0

The z.6 and 2.5 m³/h models initially showed moderate leakage, but the rate gradually decreased with more test repetitions. This trend was likely caused by improved internal sealing or mechanical stabilization after repeated activations. In contrast, the 4 m³/h valve showed no measurable leakage in any of the tests, indicating a highly effective sealing design and consistent performance. The 6 m³/h model, however, showed variable results with no clear stability in leakage rate.

Table 9 and Figure 7 only show the average leakage rate for each EFV model, measured in micrometers cubed per second (µm³/s).

Table 9. Average Measured Leakage Rate for Different EFV Types

	1.6 m³/h EFV	2.5 m³/h EFV	4 m³/h EFV	6 m³/h EFV
First Series EFV	1.2376	0	0	0
Second Series EFV	0.1526	0.204	0.055	0.046

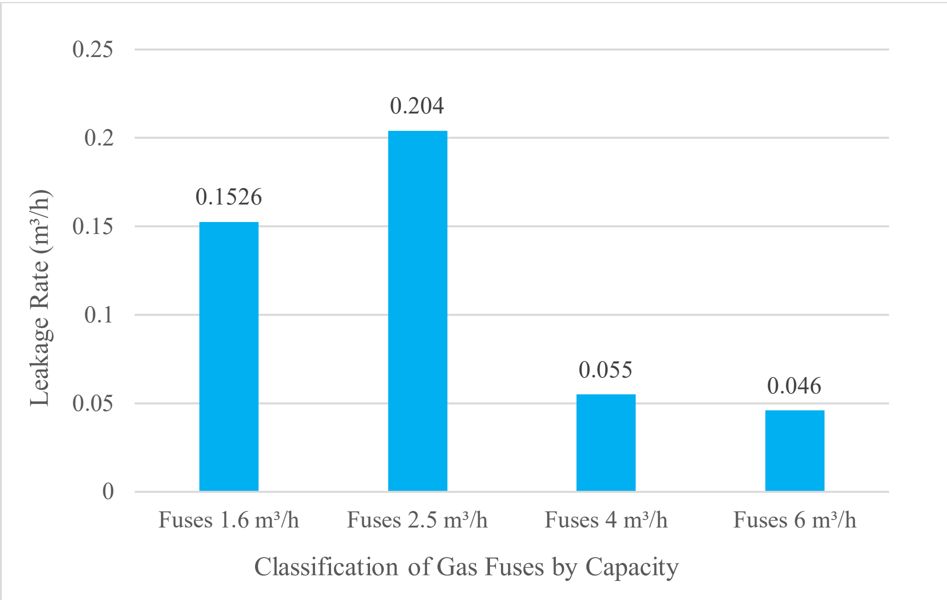

Figure 7. Average Gas Leakage in Different Fuses

In this comparison, the 1.6 and 2.5 m³/h models had relatively high average leakage, while the 4 m³/h valve had a near-zero leakage rate across all test cycles. For the 6 m³/h model, however, its performance cannot be reliably assessed based on Table 9 or Figure 7 alone, because of the high variability in its data details that can only be seen in Tables 5 through 8.

These results make it clear that a valve's ability to control leakage depends on more than just its size. Things like how it's built, how well its internal components are designed, and how it performs under stress all play a role. That's why, when choosing EFVs for gas networks—especially in places where safety really matters—it's not enough to look only at the rated flow capacity. It's just as important to know how the valve behaves over time, how reliable it is after repeated use, and whether it might still allow small amounts of gas to leak through under low-flow conditions.

Taken together, the findings in this section support what earlier safety studies have shown about Tehran's gas infrastructure: threaded joints and service lines are some of the most vulnerable points during an earthquake. Since upgrading the entire system would be expensive and technically difficult, using EFVs—especially models that show stable, low-leakage performance—can be a smart and affordable way to strengthen the safety of these high-risk areas.

5.3. EFV Shut-off and Reopening Behavior Under High Pressure

The performance of all EFV models was also tested under elevated pressure conditions (80 psi) to better understand how pressure influences their behavior. The tests were carried out using two different setups, as described earlier in Section 4.3.

In the first setup, where no pressure regulator was used, all EFVs successfully shut off the gas flow once the rate exceeded about 70% above their nominal capacity—similar to how they behaved under low-pressure conditions. However, after the valves were activated, none of them reopened. The reason was the high pressure difference across the valve, which made it difficult to balance the forces needed for automatic reset.

In the second setup, with the EFV placed upstream of a pressure regulator, two outcomes were observed. In some tests, the valve closed almost immediately after flow started. In others, the downstream flow went far beyond the EFV's rated capacity before activation. For example, the 2.5 m^3/h model allowed flow to reach about 11 m^3/h before shutting off. Although this is still considered acceptable in terms of safety, it shows that the pressure regulator changes how the valve responds. Similar to the first setup, none of the valves reopened after shut-off in this configuration either.

Overall, these results suggest that EFVs still do a good job shutting off the flow when pressure gets too high. However, reopening the valve after it shuts off seems to be a challenge in these conditions. Also, where the valve is placed—especially in relation to components like pressure regulators—can change how and when it reacts. These findings show how important it is to think carefully about pressure changes and how the system is set up when using EFVs in high-pressure parts of a gas network.

6. Conclusion

Given the development of urbanization and the increasing density of cities against natural disasters such as earthquakes, strengthening the resilience of urban infrastructure systems, including urban gas distribution infrastructure, has become one of the critical priorities. Considering the high costs, complexity, and operational limitations of extensive renovations of urban gas infrastructure or the development of remote shut-off systems, the use of excess flow valves (EFVs) is considered a practical and immediate method for risk reduction.

This study demonstrated that EFVs can effectively shut off gas flow during sudden surges caused by simulated pipeline failures, even at both low and high pressures. Among the tested models, the 2.5 m^3/h EFV showed the most stable leakage control and consistent self-resetting behavior, making it a strong candidate for real-world deployment. In contrast, the 6 m^3/h valve exhibited erratic performance, particularly under low-pressure conditions.

The experiments also revealed that EFV reopening is limited under elevated pressure due to an imbalance across the valve—especially when no mechanisms are in place to equalize pressure. This was further influenced by the valve's location in the system, such as whether it was placed before or after the regulator.

These hands-on results—gathered from more than 170 test cycles for each valve—highlight just how important it is to think carefully about where and how EFVs are installed. The layout of the system and how pressure behaves across different parts both play a big role in how well these valves perform in practice.

The combination of passive operation, self-contained response mechanisms, and simple deployment makes EFVs a compelling and scalable option for reinforcing gas network safety in seismic environments. Still, before they can be widely used, it’s important to test them in different real-world situations. Doing so will help fine-tune how they’re chosen and installed—and ensure they work well outside the lab too.

7. Recommendations

Based on the results of this study and the known weaknesses in the urban gas system, especially in high-risk areas, the following points are suggested for practical and short-term action:

Install EFVs after the regulator:

These valves worked well with low-pressure gas after the regulator. They can stop gas in case of big leaks, like when a pipe is broken, a valve is opened to the air, or something gets disconnected during an earthquake. Using EFVs based on the gas meter size can help reduce gas leakage inside damaged buildings.

Use EFVs at the riser, after the main shut-off valve:

Even though there isn't enough test data for high-pressure conditions before the regulator, installing EFVs right after the meter shut-off valve (meter-stop valve) could help protect against leaks from damaged joints. It's technically better to place the EFV before the shut-off valve, but that's harder to do while gas is flowing. After the valve is easier and safer.

The 2.5 m³/h model is the most reliable:

Among the models tested, the 2.5 m³/h EFV worked the best in both stopping and restarting the gas flow. This model is a good choice for pilot testing and early installations.

Start with a pilot project:

Running a pilot project in a real neighborhood will help gather more useful information—like how gas quality or different usage types affect performance. Based on that, the company can work with manufacturers to improve any weak points.

Choose the right pilot location:

Places with a higher risk of damage, like older homes with risers under roof edges or near walls, should be chosen first. For example, District 17 in Tehran could be a good area to start.

Compare the cost to other systems:

The cost of using EFVs should be compared to other options like remote shut-off systems or smart meters. If the price can be lowered—especially with local production—EFVs could be a more affordable solution for many homes.

Use EFVs as part of a bigger plan:

For long-term earthquake safety, EFVs can be part of a full protection system:

- Remote shut-off for big stations and main lines
- Automatic shut-off at local stations
- EFVs can be installed at service lines, either before or after the shut-off valve, depending on the setup.
- Pressure regulators
- Smart meters in the future
- Small EFVs at each appliance or burner point

8. References

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