JOURNAL OF GAS TECHNOLOGY
Volume 7 / Issue 1 / Summer 2022 / Pages 70-85
Journal Homepage: http://jgt.irangi.org

Simulation of the Natural Gas Pipeline Explosion by Using PHAST Software and Investigation of Line Break Valve's Effectiveness

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ARTICLE INFO

ORIGINAL RESEARCH ARTICLE

Article History:
Received: 14 June 2022
Revised: 19 August 2022
Accepted: 15 September 2022

Keywords:
Pipelines, Gas
PHAST
Automatic valve
Line Break Valve (LBV)
Consequence

DOR: 20.1001.1/jgt.2023.555757.1001

ABSTRACT

Two points need to be taken into consideration regarding buildings built around gas transmission pipelines in Iran, first, the density of the buildings and second, the distance from the axis of the pipeline. These values are determined by standard tables IGS-C-SF-015. Nevertheless, determining the two mentioned factors is not enough to determine the risk level of threats caused by gas pipelines explosion. The best way to calculate the risk level that threatens buildings around pipelines is by using computer calculations such as PHAST software to estimate the consequences of accidents and analyze the results based on natural accidents. However, it is worth mentioning that the PHAST software also cannot calculate the effects of soil in the explosion of burial pipes. Hence, the simulation by PHAST for an explosion-exposed gas pipeline can be a basis for other evaluations. After determining the appropriate consequence modelling, the effectiveness of using equipment that can reduce the explosion's consequences is also investigated. In this paper, after logical modelling for the real explosion, the effectiveness of a standard protective device in gas pipelines called Line Break Valve (LBV) for reducing the explosion's consequences is measured. At first, the probability of the LBV functioning at the time of the explosion is checked. Subsequently, by the diagram, the consequences of the accident for two modes of operation and non-operation of the LBV system are displayed and compared with each other. Ultimately, for the simulated mode, it is observed that the correct operation of the LBV system could reduce the accident consequences by more than 60%.

How to cite this article
M. Doustmohammad, S.M. Mirhosseini, E. Zeighami, H. Lajvardi, Simulation of the Natural Gas Pipeline Explosion by Using PHAST Software and Investigation of Line Break Valve's Effectiveness. Journal of Gas Technology. 2022; 7(1): 70 -85. (https://jgt.irangi.org/article_707113.html)

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Available online 22 September 2022

1. Introduction

Gas production and transmission need to be associated with three factors: safety, cost and sustainable development and inevitably to manage this vast and developing network, arrangements require to be made to balance these factors. The importance of safety and coordination with other factors in gas pipelines is displayed in (Figure 1) (Antaki George A., 2003).

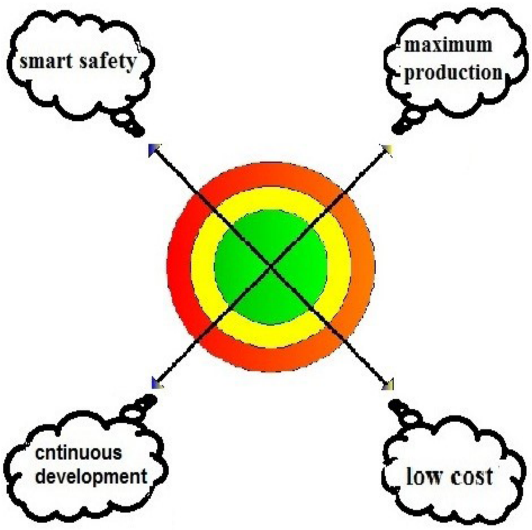


Figure 1. Main factors of Efficiency (Antaki George A., 2003)

Risk calculation is the conclusion from the probability of an incident occurring and the consequences of the incident. For only one type of threat (ASME B31.8S, 2020):

$$Risk_i = P_i \times C_i \quad (1)$$

C = failure consequence

P = failure likelihood

It is necessary to determine the values of C and P as much as possible to know the interaction between the environment and the gas pipeline on each other. (Muhlbauer, W. Kent, 2004) The location class is defined based on human communities and buildings around the lines. According to the location, classes are determined by the thickness of the pipe and the distance between the valves. (ASME B 31.8 standard, 2022). Nonetheless, after 2018, replacing the pipe with a higher thickness is no longer necessary to upgrade the location class. (PHMSA, 2018)[1]. Furthermore, ASME[2], explicitly states that the efficiency of automatic valves for risk calculations is not considered, but this effect can be calculated and considered by experts[3]. Moreover, PHAST software alone cannot consider the effectiveness of the automatic shut-off valve. Meanwhile, when an accident occurs in the gas pipeline, the speed of gas flow interruption is essential[4] (FEMA, 2003). Common methods for determining the safe distance from the pipeline axis are:

- Potential Impact Radius (PIR) formula
- Iranian Gas standard (IGS-C-SF-015)
- Software

In this study, the safe distance for the gas pipeline (which has had an accident) is calculated and checked from all the above three methods and for the first time, it has been tried to identify the effectiveness of the LBV system and then its effect in the gas pipeline risk assessment.

(Figure 2) illustrates a schematic of the incident. Around 11:45 on 10 September 2010, during the implementation of the 48″ Turkmenistan-Sangbast pipeline, this line needed to pass from under the first and second 36″ gas lines Sarkhes-Mashhad, due to the fall of a side-boom on the Second line, a bursting has occurred. The gas leak covered the entire workplace, and then the explosion killed 16 people, injured 14 people, and destroyed the machinery and equipment.

1. PHMSA have suggested that performing PIMS where class locations have changed due to population increases would be an equally safe but less costly alternative to the current requirement of reducing pressure or replacing the pipe

2. ASME B31.8/846.2.1-d

3. ASME B31.8S-2020-5.5(b) (1)-Subject Matter Experts (SMEs).

4. When a gas pipeline explodes, one-third of the chemical energy is released at the initial explosion, and the remaining two-thirds is released slowly. Detonation products mix with air and burn. On the other hand, prolonging the leak time too much can affect some areas that were not damaged at the initial moment of the explosion. Therefore, from periodically, there is a possibility that the second part of the incident will cause far more significant consequences than the initial explosion.

2. The incident

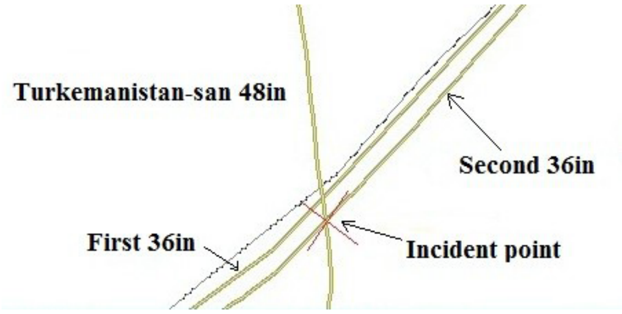


Figure 2. Location of the blast site

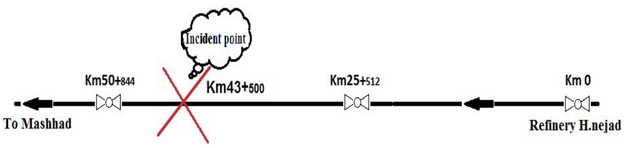


Figure 3. Schematic of the LBV's

(Figure 2) and (Figure 3) illustrates a schematic of the incident. Around 11:45 on 10 September 2010, during the implementation of the 48" Turkmenistan-Sangbast pipeline, this line needed to pass from under the first and second 36" gas lines Sarkhes-Mashhad, due to the fall of a side-boom on the Second line, a bursting has occurred. The gas leak covered the entire workplace, and then the explosion killed 16 people, injured 14 people, and destroyed the machinery and equipment.

- The distance between two 36" lines is about 16m.
- The 48" pipeline channel was about 4 meters deep and 3 meters wide.
- The side-boom is about 70 tons.
- At 11:54 a.m., the LBV valve at 51 km was closed immediately after the explosion.
- At 12:18, the valve of zero kilometer of the new line 36" was closed by manpower.
- At 13:35, according to witness reports, fire could be observed at the scene.
- At 13:56, from 51 km gas purged (open vent valves and gas vented into the environment)
- At 14:05, closed valve at 25 km, and the purged the line.
- The area under explosion is about 10^5 m^2

(Tables 1 to 3) explain the details

Table1: Gas Components 36" Liness

Component	Mole percentage
Nitrogen	0.56
Carbon dioxide	1.00
Methane	97.66
Ethan	0.61
Propane	0.10
Isobutane	3.47
0.01	0.78
Normal butane	0.03
Isopentane	0.01
Normal pentane	0.02

Table 2: Properties of air and natural gas

Natural Gas	Air	Specifications
0.688	1.205	Base density (kg/m^3)
1.304	1.4	Specific heat ratio
1700	717.3	Heat transfer coefficient in constant volume (J/kgK)
288.2	288.2	Base temperature (K)

Table 3: Explosion Incident Modeling Information

Gas pipeline specifications	Description	pipe specifications	Description	Conditions	Description
Gas pressure	930-1000 Psi	Material and standard of the pipeline	API 5L X 60	Distance from gas control valves	18 km from upstream and 8 km from downstream
Gas temperature	313 k (40 C)	Pipe thickness	0.562 in	How the incident happened	Perforation, severe leakage and explosion, respectively
Gas flow	35, 280, 770 m^3/day	Location Class	B	Explosion profile	JET fire & Detonation
Ambient air profile at the time of the incident	2010 sept 10, Friday 11:45 PM	Pipeline distance to ground level	4 meters - in free surface mode	Approximate radius of degradation	180 m
Environment temperature (T)	30 C	Distance between existing pipelines	18.6 m - several parallel lines	Enclosed in soil / free surface	free surface
Relative humidity	17%	Effective pipeline length	51 km	air pressure (P)	91kPa

3. Potential Impact Area(PIR)

One method to calculate the consequences of a gas pipeline's possible incident and to estimate the area affected by the damage caused by it. Its pressure is not more than 1450 psig (10 MPa), and its temperature is not less than 0 °C (32 F). Formula (2) can be used to estimate the explosion radius: (ASME B31.8S, 2020)

$$r = 0.69d\sqrt{P} \qquad (r = 0.00315\, d\sqrt{P}) \qquad (2)$$

While:

d = outer diameter, in. (mm)

P = (MAOP) Maximum allowable working pressure, psig (kPa)

r = potential effect radius, ft. (m)

Using the formula (2) the explosion radius for line 36" in pressure 1000psi:

$$r = 0.69 \times 36 \times (\sqrt{1000})$$

$$r = 785.51\ ft = 239.423\ m \approx r = 240\ m$$

In (Figure 4), which is adjusted according to the formula (2), for gas pipe 36" in 7000kPa (1000psi) is approximate radius 243m.

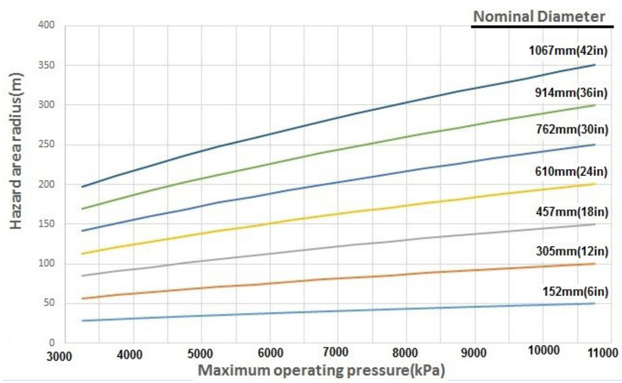


Figure 4. Proposed Hazard Area Radius as a Function of Line Diameter and Pressure (K. Moore, 2002)

4. The Legal Distance

Although increasing the thickness has an effect on reducing the probability of an incident and although increasing the thickness reduces the probability of an incident and thus reduces the risk, it has almost no effect on the consequences. Due to population growth and industrial development, legislators should consider a safe distance from the pipeline axis according to the type of buildings. Risk calculations can help them determine this distance. According to the IGS standard, the maximum distance considered safe from a 36” gas pipeline with a design pressure of 1050 psi is 200 meters. In accordance with (Table 4) and by comparing this distance and the incident distance calculated in section 3, it can be seen that the maximum legal distance considered for the pipeline is 40 meters less than the calculated PIR Distance.

Table 4: Safety zone for prohibition of construction from the pipe axis (meters) for a nominal diameter of 32 to 38 inches

Type of buildings	Maximum allowable operating pressure	Design coefficient			
		0.72	0.6	0.5	0.4
Buildings are a gathering place and dangerou	400-1050 (lb/in^2)	200	200	40	20
For ordinary buildings with design factor D	900-1050 (lb/in^2)				20
For ordinary buildings with design factor C	900-1050 (lb/in^2)			40	
For ordinary buildings with design factor B	900-1050 (lb/in^2)		55		
For ordinary buildings with design factor A	900-1050 (lb/in^2)	70			

Summary of values in Tables 1-5(IGS-C-SF-01) for 36” pipe.

5. Software

The consequence or “leakage factor “calculation depends on two factors.

1. Thermodynamic and composition properties of gas (up/downstream) in the pipeline
2. The environment around the pipeline

Due to the large number of variables, the scope of their changes, and the complexity of the interactions of these two factors, the best way to consider the above two factors in consequence calculations is to use computer software. The following four steps need to be taken in order to evaluate the consequences of an incident by using PHAST software: (Colin, Hickey, 2016)

1. Scenario determination
2. Possible mode selection
3. Incident modelling
4. Damage assessment

Preferably, it is necessary to consider a suitable and probable scenario(s) to simulate an incident. To this aim, a real accident can be used as a suitable scenario and as a basis for selecting other scenarios to localize the basic risk assessment model. In this paper, as much as possible, the selected variables for simulation are tried to be similar to those observed in the real incident of the Sarakhs-Mashhad line. After that, the obtained results are used for two purposes: To compare the consequences of the real scenario with other possible scenarios and to identify and calculate scenarios that PHAST software cannot calculate. Such as the effectiveness of LBVs in gas pipelines. Choosing this incident is suitable for simulation because the desired software:

- Because the PHAST cannot dedicate models for underground pipe rupture (Karim, OSMAN, 2016)
- Absence of structures in the radius of propagation of the incident wave
- Lack of significant vegetation around the pipeline
- The surrounding environment is relatively flat and without obstacles

Challenges of incident simulation:

Although the above comparative advantages increase the probability of convergence of modelling results with the severity of the actual incident, it is impossible to accurately match the consequences of the incident with the software results.

- It takes over 3 hours to see the flame until it is extinguished. Changing the weather conditions, such as changing the angle and intensity of wind, is possible. This can cause the radius of the incident to be asymmetric, especially at distances far from the incident site.
- Purging the gas from the beginning and end points may have reduced the severity of the consequences of the accident to some extent
- Hypotheses: The following assumptions are considered to minimize the difference between the simulation results and the real accident outcome:
- based on the available evidence, the area under the influence of damage caused by the incident is determined, and then the
- Radius of the incident is considered based on that area.
- The incident boundaries are considered symmetric, and the incident severity is based on this symmetric distance.
- The radius of the incident is considered according to the most dangerous severity of the effect observed at the scene of the incident

Determining the incident scenario:

In PHAST software, depending on the type of facilities and materials used in them, different scenarios are considered for different types of incidents:

- Release of toxic substances
- Explosion
- Ignition

In general, for a pipeline carrying natural gas flow, due to its non-toxic/non- allergenic nature, for natural gas (which mainly contains methane), incident scenarios are considered only based on explosion and ignition.

(Table 5) shows all the possible states of the accident and the probability of each. In such a way, the states with a low probability of occurrence are marked with yellow color, the states with a high probability of occurrence are marked with green color and the impossible states are marked with red color. BLEVE, CE modes for explosion and Spherical fire and Pool fire for ignition are likely to occur only if the fluid is liquid, and dust explosion mode requires the presence of flammable dust particles in the air (ISSA, 2004). So what might happen is:

- Vapor Cloud Explosion (VCE)
- Flash Fire
- Jet Fire

Table 5: Probability of natural gas accidents

FIRE	EXPLOSION
FLASH FIRE	VCE
FIRE BALL	BLEVE
JET FIRE	CE
POOL FIRE	DUST

High probability
Likely
impossible

It is essential to mention that Flash Fire cannot release significant energy and does not create a pressure wave. VCE is created in conditions where: closed spaces, spaces with sufficient obstacles or gas flow in the atmosphere can become “gas clouds”. The explosion radius in the VCE mode is caused by a balanced and explosive mixture of gas and air, which largely depends on the environmental conditions in the open space. (Naemnezhad, Abolfazl., 2017) However, according to the remains and observations made from the incident area, it is observed that the primary damage was caused by fire. Ultimately, it is necessary to perform a simulation for three possible accident situations.

Gas leakage and determination of different states and assumptions:

In determining possible scenarios caused by gas, one essential factor in determining the shape and amount of leakage. According to objective observation, the initial leakage was due to a 70-ton side boom falling from a distance of 3 meters and falling on the pipe. The IGT / AGA formula needs to be used to calculate the amount of gas available and determine the approximate amount of flammable or explosive gas[1]. The amount of gas available in the distance from the place of rupture of the pipe to the valve 51 km downstream (distance about 8 km) in case of immediate operation of the LBV is approximately 387,453 m3(actual value is 368,143 m3), which in case of a complete rupture in the first moment, time of discharge are about 140s to 350s, according to formula (3). (A.G.A, 2020)

$$T = \frac{(0.0588)(P_1)^{1/3}(G)^{1/2}(d^2 LF_C)}{d_b^2} \quad (3)$$

T	Discharge time (minutes)
$P_1 = 930\ (PSI)$	Gas pressure
$G = 0.688$	Gas density
$d = (36\text{-}2\times0.562)$	Gas density
$d_b = d$	The ID of drain pipe[2]

$L = 8\ Km = 5\ (mile)$ The length of the discharge pipeline

FC Valve clotting factor is considered between 1 and 2.5

$$\frac{(0.0588)(930)^{1/3}(0.688)^{1/2}\times(5)\times(34.876)^2\times1}{(34.876)^2} = 2.38$$

$T = 138\ s$ $Fc = 1$

$T = 345\ s$ $Fc = 2.5$

A comparison of the calculated time with the actual conditions shows that the explosion and complete cutting of the pipe section did not occur in the first minutes. On the other hand, considering the size and strength of the pipe in (Table 3), it seems unlikely that a pipe with a yield strength of 60,000 psi and its joints have been hydrostatically tested up to 1150 psi, While the two ends of the pipe are also semi fixed , had been fully ruptured in the early moments of the accident. Consequently, we assume the average upward leakage rate in the initial moments of the side-boom fall and then compare the results with the observed objective consequences.

The intensity of the pressure drop has caused the LBV to be activated at 51 km. The corresponding amounts of gas are discharged from each of these points. The minimum gas output from the upstream incision site (due to the closing valve and discharge from 0 and 25 km) by formula 4 is estimated at 1,002,548.955 m^3 (actual value is 936,689 m^3). (A.G.A, 2020)

$$V_b = V \times (T_b/P_b) \times (P/T) \times (Z_b/Z) \quad (4)$$

V_b	Gas Value (m^3)
$V = 15405\ m^3$	Pipe value
$T_b = 519.67\ R$	Base temp
$P_b = 1.013$	Base pressure
$P = 64\ bar$	Gas pressure
$T = 563.67\ R$	Gas temperature
$Z_b = 0.998429$	Base Compressibility factor
$Z = 0.893594$	Compressibility factor

According to the values of Tables 1, 2, and 3, it is possible to calculate the maximum rate of gas exit from the incident pipe and determine the required software values by converting the units. Average gas passing through the pipeline involved in the incident: Total volume of available gas: is the sum of exhaust gas from the sides of the rupture:

$$35،280،779\ \frac{m^3}{day}$$

is the sum of exhaust gas from the sides of

1. The inaccuracy of the pressure gauges and the long length of the gas pipeline creates the possibility of the inaccuracy of the pressure, so adjusting the numbers after each simulation according to the results and following the available evidence.

2. The inner diameter of the drain/vent pipe, which is equal to the inner diameter of the pipe in the case of full rupture

the rupture: Maximum gas outflow rate

$$368{,}143\ m^3 + 936{,}689\ m^3 = 1{,}304{,}832\ m^3$$

Maximum gas outflow rate

$$35{,}280{,}779\ \frac{m^3}{day} \times 0.688(kg/m^3) = 23{,}567{,}554.3\ \frac{kg}{day}$$

$$= 272.77\ kg/sm^3$$

Correspondingly, depending on the side-boom's hit, the release angle was considered vertical (of course, there was a possibility of changing direction in the following moments)

The results of PHAST software calculations for the two modes of closing the LBV in the 60s (ideal mode) and the state without operation of the LBV to closing by human resources (similar occurred in the actual incident) together are compared and then compared different weather conditions with existing (real) conditions. It takes at least 40s-50s from the explosion to close a 36" valve completely.

Explosion:

(Figure 5) and (Figure 6) show the actual geographical position around the explosion site, and the roughness of the earth's surface is displayed in specific radii, respectively.

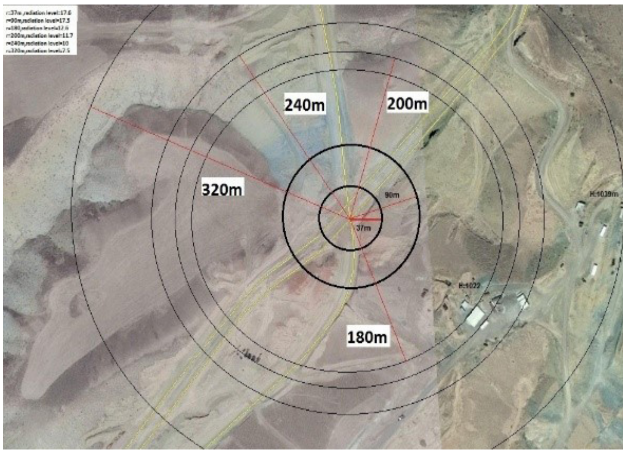


Figure 5. Geographical location

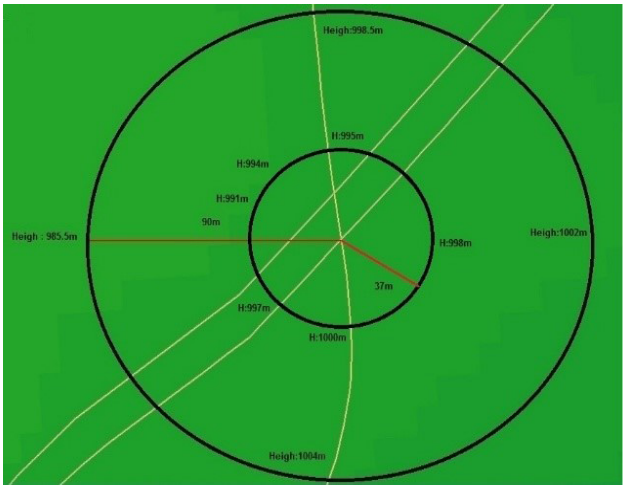


Figure 6. Changing ground levels

Table 6. damage Approximations (FEMA 426, 2003)

Incident Overpressure (psi)	0.15-0.22	0.5-1.1	1.1-1.8	1.8-2.9	Over 5	4-7	6-9	10-12
Damage	Typical window glass breakage	Minor damage to some buildings	Panels of sheet metal buckled	Failure of concrete block walls	Collapse of wood framed buildings	Serious damage to steel framed buildings	Severe damage to reinforced concrete structures	Probable total destruction of most buildings

It will be seen that the existing roughness is not significant enough, and It has no effect on the intensity of harmful factors (especially the intensity of radiation) caused by jet fire. The destructive effects of the explosion are due to the increase in pressure. The severity of damage in terms of blast pressure is according to (Table 6) (KINNEY & GRAHM,1985). This table shows that for increasing the pressure by more than 1 bar (14.504 psi), probable destruction of most buildings, nevertheless, even at lower pressures, damages are caused too. (Figure7 and Figure 8) show the explosion pressure distance above 1 bar and how to reduce it, respectively, for LBV that stays open for 3 hours and the state of LBV that closes within the 60s after the incident. In the following, the severity of the incident for the two mentioned cases in the worst possible case is compared (Figure 9) and (Figure10)

A) Intensity of damage due to explosion

For the desired 36" line:

- Explosion radius when the valve is open: 108 meters (Figure 7)

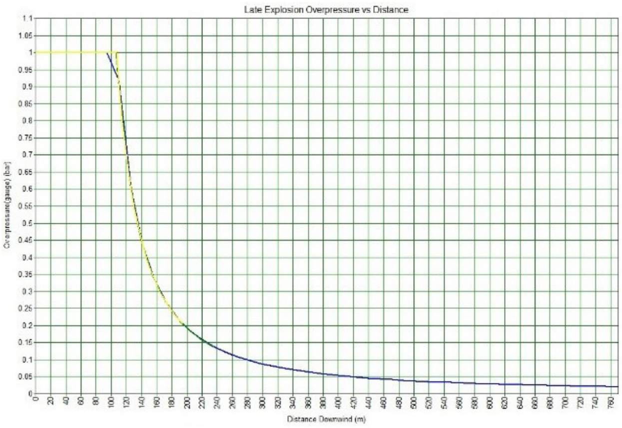


Figure7. The effect of over pressure (Explosion) when the valve is open

- Explosion radius when the valve is closed: 68 meters (Figure 8)

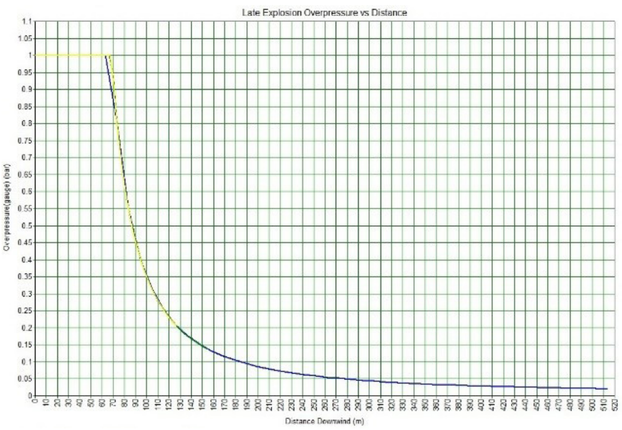


Figure 8. The effect of over pressure (Explosion) when the valve is closed

B) Worst possible explosion mode:

- The worst possible radius of explosion without valve operation (open valve in real time) (Figure 9) is about 190m to 850m.

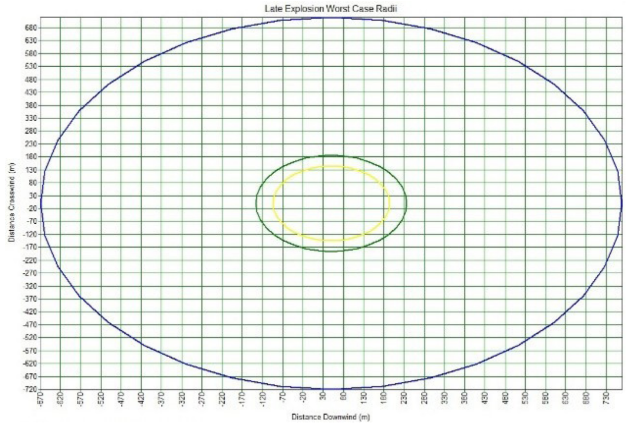


Figure 9. Worst possible explosion mode for opened valve

- The worst possible radius of the explosion, when the valve is closed in less than the 60s (Figure 10), is between 122 m and 520 m.

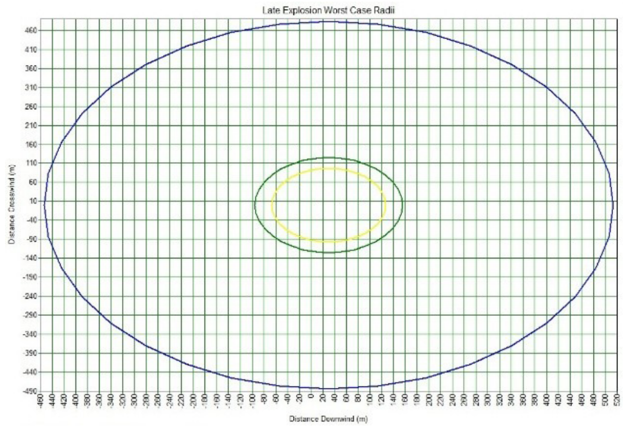


Figure10. Worst possible explosion mode for opened valve

Flash Fire:

The radius of Flash fire when the valve is open (Figure 11) is 20 m (for the amount of gas at the rate of mixing 4.4 ppm) to 54 m (for the amount of gas at the rate of mixing 2.2 ppm) and flash fire radius when the valve is closed (Figure 12), between 13 m (for the amount of gas at mixing 4.4 ppm) to 36 m (for the amount of gas at the rate of mixing 2.2 ppm) the mixing rate for continuous gas ignition starts from at least five ppm, damage at intervals calculated for Flash fire has much explosion modes. The explosion and Jet fire cover the destructive area of Flash fire.

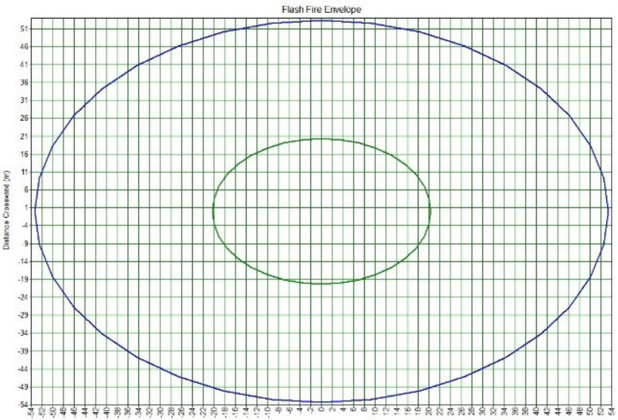


Figure11. Flash fire radius for opened valve mode

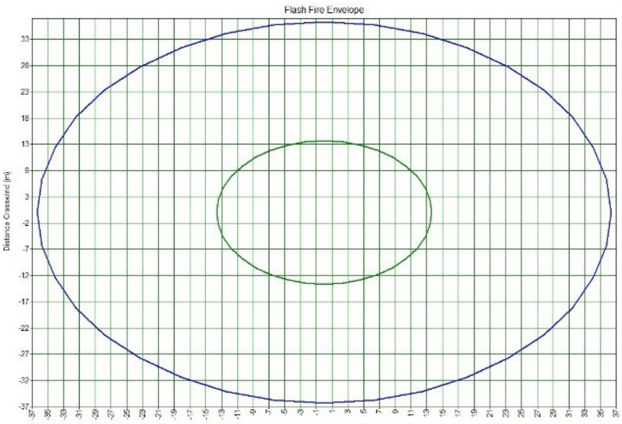


Figure 12. Flash fire radius for closed valve mode

Jet fires:

The approximate radius of the destruction effect can be obtained from (Figure13).This diagram is based on the experimental results of Jet fire destruction in the United States for sizes between 14" to 36" and pressure 575 psi to 1200 psi. (S. Haklar, James., Densnak, Robert.1999) For example, pressure of 1000psi, the burn radius will be:

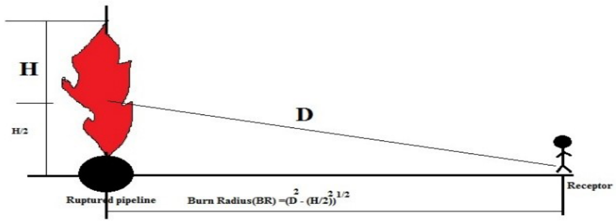
$BR = 680\,ft. = 207\,m$

$$Burn\ Radius\ (BR) = (D^2\text{-}(\frac{H}{2})^2)0.5 \qquad (5)$$

D: Distance from the flame center to the observer

H: Flame height

Using Formula (5) and the approximate and hypothetical minimum value D = 220 m, the value H = 150 is calculated. Comparing the amount of minimum height calculated for the flame and the changes in height and terrain features from (Figure 6) it results that the flames are so high that they have been able to emit their thermal radiation beyond the terrain. On the other hand, some eyewitnesses have claimed that they have seen the light from the incident flame from a distance of 64 km, in which case the height of the flame can be considered much higher than the estimated and minimum calculated value, and this means that terrain features could not create a significant obstacle in the development of ignition radiation. According to the incident report, the gas flow and, in other words, the ignition fuel supply continued for about 3 hours.



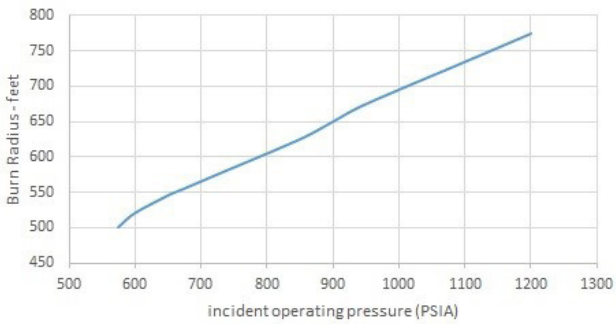


Figure 13. Radiation degradation of flame radiation

Intensity of radiation effect (Heat flux value):

The extent of the damage for different amounts of heat flux is shown in (Table 7). (Mark J. Stephens, 2002) the intensity of the effect in the closing mode of the valve (Figure 14) up to a radius of 105(m) is 12.5 (yellow diagram) and up to a radius of 345 (m) is 4 (green diagram), and the intensity of the effect in the open state of the valve (Figure 15) is up to a radius of 180(m) is 12.5 (yellow diagram) and up to a radius of 520 (m) is 4 (green diagram). Immediate operation of the automatic valve (in 60 seconds), and the area under damage was 3.5 hectares.

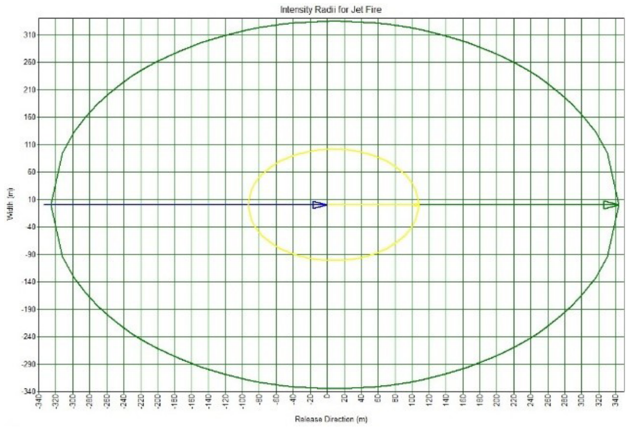


Figure 14. Jet fire effect for closed valve mode

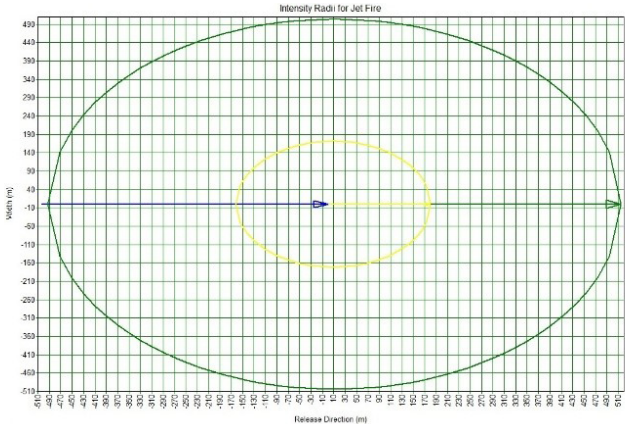


Figure 15. Jet fire effect for opened valve mode

Thermal radiation changes in radial distance:

Table 7. Vulnerability to heat (Mark J. Stephens, 2002)

Thermal radiation (kw/m^2)	1.2	2.1	4.7	6.3	9.5	12.6	15.6	23	35	37.5
Description	Received from the sun at noon in summer	Minimum to cause pain after 1 minute	Will cause pain in 15-20 second and injury after 30 s	Serious injury after 1 minute but the body is protected by clothing	Damage and the possibility of ignition in a few seconds	Deadly damage and heat generation to the extent of wood flame	Damage to structures and low chance of taking refuge	Damage to unprotected metal equipment	Cellulose material catches fire	Any equipment will be damaged

(Table 7) shows the intensity of damage in the ignition state is due to the intensity of the radiation effect. For closed valve mode (Figure 16), the maximum radiation intensity is 16.5 kw/(m^2) at 40 m and for opened valve mode (Figure 17), 18.5 kW/(m^2) at 60 m. for closed valve mode at radius of 110 m, the amount of radiation intensity is 12.3 kw/(m^2), and if the valve is left open, the same radiation intensity reaches a radius in 180 m.

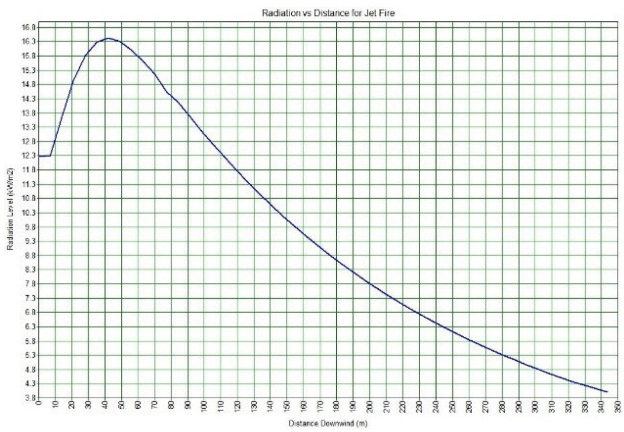


Figure 16. Max of intensity is 16.5(kw/m^2) for closed valve mode

Figure 17. Max of intensity is 18.5 (kw/m^2) for open valve mode

6. The effect of atmospheric conditions

In (Figure 18), the explosion radius diagram from the increased pressure. In (Figure 19), the explosion worst state diagram and (Figure 20), the intensity of the immediate fire effect diagram, are shown for different atmospheric conditions so that for condition (1.5D- blue diagram), the radius of wave can able extended to 2500 m (Figure 18). The possibility of such weather in the incident area and at the time of the incident is very far from conceivable. Nevertheless, this example was raised to determine to what extent a lack of attention to probable weather conditions can affect the outcome assessment and ultimately distort risk management.

This means more probable conditions should be tried according to reliable weather information for a reasonable estimate. On the other hand, the effect of destruction in the real case has been seen up to a distance of about 2000 meters. However, for the reasons mentioned in Section 5, this distance has been avoided as a basis for comparisons. The radius of ignition, which has caused severe injury, has been considered the radius of the accident. That is, the potential space of severe injuries is also considered to manage the risk and consider the severity of the consequences. (Figure19) shows that in addition to the radius of the explosion, the gas mass's displacement before the explosion's moment can also be another factor in the propagation of the blast wave. (Table 8) summarizes the results of software surveys for different weather conditions and the impact of automatic valve performance.

(Figure 20) shows atmospheric conditions that could increase the instantaneous fire radius by up to 500 times. However, this atmospheric effect on the dimensions of the accident outcome is specific to the flash fire (Shuran Lyu, 2019).

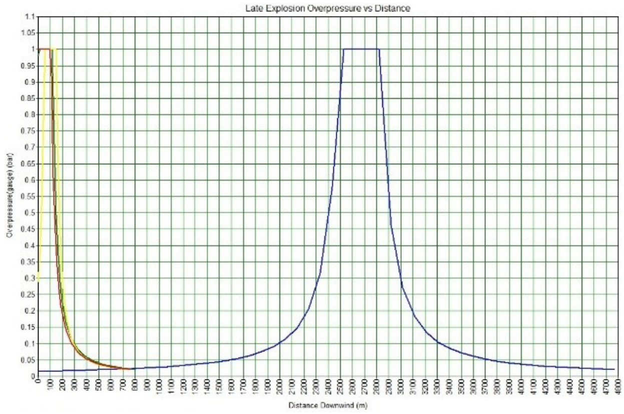


Figure 18. Increased explosion pressure for different types weather

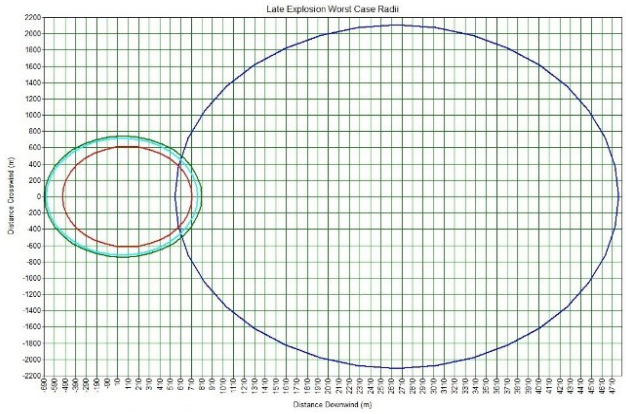


Figure 19. Worst Explosion Mode for different types weather

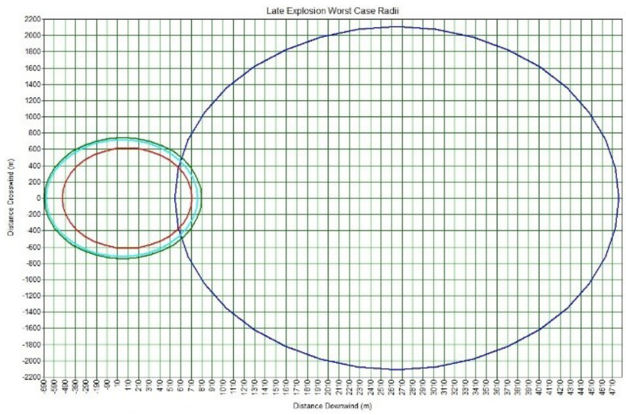


Figure 20. Flash fire for different types weather

Table 8: Comparison of weather conditions

Row	Degradation parameters (Explosion and ignition)	weather				Reduction of outcome if the valve, km25 is closed (%)
		1.5F	5D	1.5D	Real	
1	Damage radius due to increased pressure wave (m)	38	2500	150	110	108
2	Worst Explosion Radius (m)	36	4750	710	810	190 -760
3	Flash fire radius (m)	35	1050	10	10	20
4	Jet radius (m)	42	660	175	165	180
5	Thermal radiation (kw/m^2)	17.5	19.5	42	18	20
6	Damage area (104 m^2)	65	136	9.5	8.5	10

7. The effects of LBV

One of the few measures that can be taken after the explosion to reduce the scope of the damage and the consequences of the accident is to limit the gas flow of the pipeline or gas transmission network on both sides of the incident up/downstream. In this incident, the upstream LBVs can operate automatically and cut off the gas flow after detonation. LBV can operate with the help of a fully mechanical mechanism. In the previous diagrams, the effect of this malfunction was compared with the ideal mode, i.e. the operation of this system and the closing of the upstream valve in less than 60 seconds. Another critical issue is the reliability of the operation of this system and, ultimately, the possibility of closing the valve at the time of the incident, for the possibility of operation of this system. The most critical parameter that must be considered is the Determination and adjustment of LBV, proportional to the pressure drop rate (PDR) of the gas pipeline when the accident occurs because, outside the PDR range, the LBV system is not able to recognize the accident and is not able to cut off the flow.

(Figure 21) shows the PDR at the downstream valve location, less distant from the incident site(8km), is significantly higher than the upstream valve location, located 18 km from the incident site (The derivative of the yellow graph is greater than the derivative of the blue graph), in the first 100 seconds after the explosion, there is no noticeable change in the upstream gas pressure due to the effect of compression forces of the gas inside the pipe, and this will be a reason for the very low probability of closing the upstream valve in less than 60 seconds. Closing the valve during the mentioned time significantly reduces the explosion consequence, so with the existing automatic shut-off mechanism, such a performance is practically impossible. The start time of the valve is at best after 100 seconds, and the cut-off time from Equation (6) is calculated:

100s + valve operation time (VOT) = flow interruption time (6)

100s: Delay time until receiving PDR signal

VOT: According to the manufacturer's instructions

The proper closing time for a 36" valve is usually between 30 and 50 seconds, and according to Equation 6, the minimum shut-off time is estimated at 130 to 150 seconds.

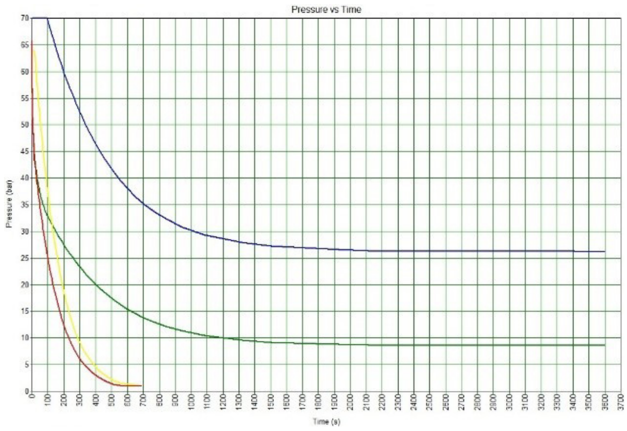


Figure 21. PDR for open valve mode

(Figure 22) shows the rate of PDR at the upstream valve location over time after the explosion.

After the explosion for 100s, there is no pressure drop at the 25 km valve, then from 100s to 150s, the maximum PDR is slightly more than 6 bar/min (drop is 6 bar in 55s). According to IGS-M-IN-304 standard, the allowable range of pressure drop rate is between 0.5 to 6. However, it is observed that placing the LBV setting at point 6 is the limit of the simulated explosion and considering that the feeling of PDR due to the explosion in the existing system is mechanical; Firstly, its precise adjustment is not possible, and secondly, its performance reliability is low compared to digital and electronic systems. Accordingly, a set point of 6 bar/min increases the risk of LBV performance at the time of the accident. Regardless, adjusting the LBV in the PDR range of less than 4, and if the system service is performed regularly and accurately, the correct operation can be imagined for the desired automatic valve.

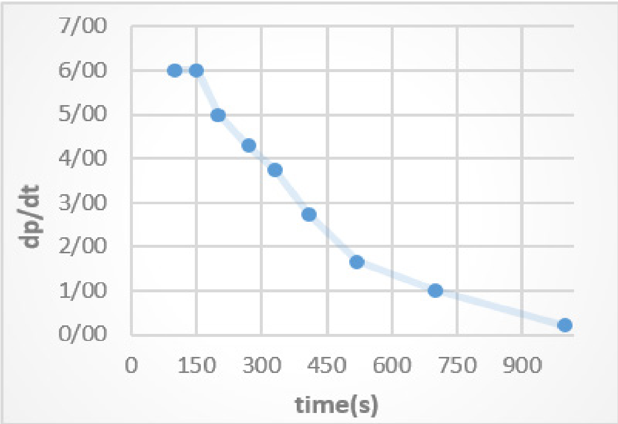


Figure 22. Pressure drop rate (PDR) over time (after 100 seconds)

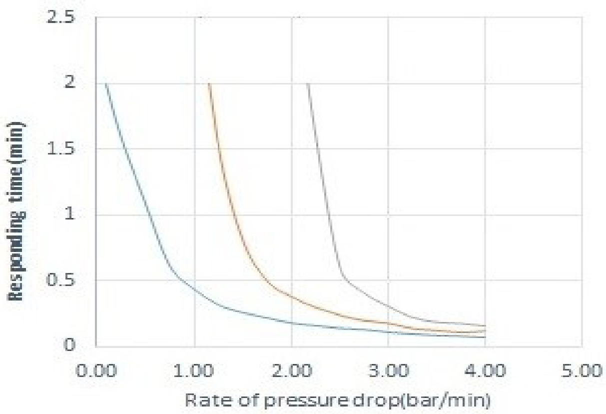


Figure 23. Example of a SCHUCK adjustment chart (MANUAL, 2008)

In (Figure 23), for this model of automatic valves, the appropriate diagram with a working pressure of 1000psi is diagram No. 2 (middle). If the PDR of 2 (bar/min) is considered for the operation of the LBV, according to the manufacturer's instructions, by receiving the cut-off response in time 22 s when adjusting and ensuring the correct operation of the automatic valve, then at the time of the incident (time 150s to 450s), the possibility of automatic valve operation was considered in the first minutes (INSTALLATION OPERATING MANUAL MAN712. 2008). In fact, the main point in this section is to understand the concept and importance of determining the gas PDR at the time of the incident in order to suitable automatic shut-off system and adjust the set point for these valves by line designers and notify operators and Consider an automatic shut-off system with a high performance factor Because, as can be seen in the real incident, not paying attention to this issue could cause the inefficiency of the automatic valve between the 50 km road and increase the destructive consequences of the incident. The choice of a mechanical system with a lower performance coefficient than digital systems and remote control by the designer and defects in service and maintenance of the way valve by the operator are the main factors in the non-operation of the upstream valve (25 km valve). Furthermore, at the time of construction and during the entire period of operation, the costs of purchase, installation, service and maintenance for the new valve at the time of the incident have been paid.

8. Conclusions

1. The approximate radius of the real incident is 180m, and the leading cause of destruction is the jet fire, which is simulated as a perfect approximation by the software.
2. Currently, the maximum distance allowed for construction permitted by law for a 36” pipeline in accordance with location class 1 is 200 meters.
3. With the help of the calculation formula of the potential impact radius (PIR), the effect radius up to 240 meters is calculated and estimated.
4. The radius calculated by the software for the specific state of the real incident (based on environmental conditions, weather, Etc.) is estimated at 108m to 190m for the explosive state, and 180m for the jet fire, which is an excellent estimate of the simulation and the power of the software is mentioned.
5. Changing environmental conditions such as burying pipes, posts or more heights around the incident, the existence of facilities and buildings around the incident site and most importantly, changing weather conditions could significantly shift the

destruction radius.

6. The essential equipment that could reduce the amount of damage after the incident was the automatic shot-off valve, which according to (Table 8), could significantly reduce the consequences of explosion and ignition, so according to studies and the Installed LBV mechanism, the following results are obtained:

   A) The probability of its operation during the first 100s of the leak, regardless of the model, type and quality of LBV used and based on the dynamics of the explosion, could be higher (or impossible).

   B) If the performance of the upstream valves were set above the IGS-M-IN-304 standard (i.e. a PDR of 6(bar/min), the probability of their performance at the time of the incident would be very low.

   C) According to the pressure drop rate calculated by the software at the valve at 25 km, it can be concluded that the dynamic conditions created by the explosion were suitable for LBV operation and, consequently, automatic shut-off system wear, lack of regular service, improper adjustment and other Reasons for wear and tear of the device and operation can be identified as the cause of malfunction of the valve at 25 km.

7. Identifying inefficiencies and replacing the LBV system with appropriate systems can significantly reduce the level of damage and consequences of the incident, reducing the level of risk and increasing productivity.

8. The costs for increasing the performance of automatic shut-off valves are much lower than the cost of changing the pipe and upgrading the class, so paying particular attention to this issue is recommended to improve integrated management.

9. According to (Figure 1), it can be seen that the installation of an inefficient automatic shut-off system disrupts the integrated management of gas pipelines by reducing safety and increasing costs.

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شبیه‌سازی انفجار خط لوله گاز طبیعی به کمک نرم‌افزار PHAST و تأثیر شیرهای خودکار بین‌راهی

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چکیـــــــده

در ایران برای احداث بنا در کنار خط لوله گاز همواره بایستی دو مسئله مورد بررسی و رعایت قرار گیرد اول میزان تراکم ابنیه و دوم فاصله از محور خط لوله گاز و این دو مورد توسط جداول استاندارد IGS-C-SF-015 تعیین می‌گردد. این در حالی است که این معیارها به‌تنهایی نمی‌توانند میزان ریسک موجود را تعیین کنند. برای این منظور بهترین راهکار استفاده از محاسبات یک نرم‌افزار معتبر مانند PHAST می‌باشد. این نرم‌افزار علی‌رغم قدرت بالای محاسبات پیامد خطر همواره برای ارائه پاسخ منطقی نیازمند ملاحظاتی می‌باشد. مثلاً این نرم‌افزار به‌تنهایی قادر به محاسبه اثرات خاک روی لوله نمی‌باشد و یا تأثیر برخی از وسایل مانند شیرهای اتوماتیک را نمی‌تواند به‌تنهایی و بدون تحلیل کاربر لحاظ نماید. در این مقاله سعی می‌شود با مدل‌سازی یک خط لوله غیر مدفون در خاک که به‌صورت حقیقی دچار انفجار گردیده مبنایی برای یک مدل منطقی تعیین شود پس از آن می‌توان اثر یک سیستم قطع اتوماتیک خط موسوم به LBV را (که در ایران برای حفاظت تمامی خطوط لوله گاز فشارقوی استفاده می‌شود) برای نخستین بار با یک دقت عملی تعیین نمود. به این صورت که پس از به دست آوردن مدل شبیه‌سازی شده انفجار واقعی، ابتدا شرایط خط را با توجه به نرخ افت فشار ایجاد شده برای عملکرد صحیح LBV بررسی نموده و پس از آن به کمک نمودار پیامدهای انفجار در دو حالت عملکرد LBV و عمل نکردن LBV مورد مقایسه قرار می‌گیرد. برای حالت حادث شده می‌توان نتیجه گرفت که عملکرد صحیح این سیستم حفاظتی تا میزان بیش از ۶۰ درصد می‌توانسته از مساحت تحت تأثیر حادثه را کم نماید.

واژگان کلیدی: خطوط لوله گاز، PHAST، شیر خودکار، پیامد