Natural Gas Release from A Containment Vessel: Basic Calculational Approaches

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Abstract

In order to assess the hazard impact of the release of natural gas from a pipeline or storage container, a computer analysis was undertaken to determine the concentration profiles and energy output during continuous and instantaneous release conditions. The Excel procedure requires the input of parameters including inside diameter, temperature and pressure of the natural gas, gas heating value, molecular weight, and wind velocity. A study of a hypothetical set of release conditions, based on data from the Petroleum Authority of Thailand, found that the radius of heat radiation with probable lethal effects was between 6 and 90 m, depending on the volume of gas. If the release occurred continuously, there was no significant impact on surrounding atmospheric conditions during the resulting fire. However, for the case of instantaneous release and explosion producing a fireball, significant and severe changes would occur, especially with respect to the atmospheric stability categories E and F.

บทคัดย่อ

เพื่อศึกษาผลกระทบอันเกิดจากการรั่วของแก๊สธรรมชาติที่อยู่ตามท่อส่ง โปรแกรมคอมพิวเตอร์นี้จึงถูกพัฒนาขึ้น เพื่อคำนวณหาความเข้มข้นของแก๊ส ในระยะทางต่างๆ ภายหลังจากการรั่วไหล ตัวแปรที่ใช้ในการคำนวณประกอบด้วย ขนาดของท่อ อุณหภูมิ ความดัน ค่าความร้อน และน้ำหนักโมเลกุลของแก๊สธรรมชาติ และความเร็วลม สำหรับกรณีศึกษาที่แสดงนี้อาศัยข้อมูลดิบจากการปิโตรเลียมแห่งประเทศไทย ซึ่งพบว่าหากมีการรั่วของแก๊ส ธรรมชาติ ระยะรัศมีที่ปริมาณความร้อนที่แผ่รังสี และมีผลต่อสิ่งมีชีวิตบริเวณข้างเคียง ให้ถึงแก่ชีวิตคือ 6-90 เมตร ขึ้นกับปริมาณของแก๊สที่รั่ว สำหรับการรั่วไหลอย่างต่อเนื่องในปริมาณน้อยๆ จะไม่มีผลกระทบต่อสิ่งมีชีวิต ในบริเวณใกล้เคียง แต่สำหรับการรั่วไหลแบบฉับพลัน การเกิดลูกไฟ หรือเปลวไฟ อาจเกิดขึ้นได้ สำหรับสภาวะอากาศที่เลวร้ายโดยเฉพาะในสภาวอากาศแบบ E และ F.

Introduction

The rapidly expanding demand for petrochemicals by the government and private sectors has made the development of the petrochemical industry a high priority in Thailand. Natural gas has been, and will continue to be, a large source of raw material for downstream production. Natural gas can be obtained from both domestic and foreign sources. Currently, there are ten or more major sources in the Gulf of Thailand and the surrounding region which includes Malaysia, Indonesia and Myanmar, as shown in ***Figure 1***. The pipeline distance in this network of sites is more than 4,000 km.

The transportation of natural gas to downstream facilities can be done by both pipeline and sea-going transport systems. Subsequently, large storage facilities are required to contain the natural gas for future use. Even though these facilities and required control instrumentation are usually designed to handle severe conditions such as high pressure, high temperature, seasonal weather changes and corrosion, the possibility of failure is always present. Prevention procedures for sudden release control and the response procedures to handle the accompanying emergency, are a mandatory part of the design and construction of such facilities.

In this analysis, a basic approach is developed to calculate the concentration and energy profiles accompanying a hypothetical case involving release of natural gas in the Gulf of Thailand pipeline network. This determination will assist the decision making surrounding the construction of a pipeline network and the potential environmental damage caused by release (slow or catastrophic) of natural gas.

In the case of natural gas leakage, two important concerns are involved: 1) whether the local concentrations of gas affect the surrounding ecology, and 2) whether the concentrations can result in fire or catastrophic explosion. The ecological effects are not considered in this analysis. The work presented here considers only aspects of the second issue dealing with the flammability and explosivity surrounding the slow or sudden release of natural gas.

The hazard potential to production pipelines and processing plants involves the exothermic oxidation of fuel in the gas phase or highly dispersed liquid phase. These reactions result in the release of heat, visible light and local pressure waves. The ignition source, availability of oxidizer, and rate of fuel flow are important factors to consider. For the assessment of the consequences of combustion, important data to be determined are the Lower Explosion Limit (LEL), the Upper Explosion Limit (UEL), The analysis of the problem is facilitated by the construction of an "event tree," to categorize the possible situations. ***Figure 2*** shows the general sequences and outcomes to be considered. Categorization includes release type (slow or instantaneous), immediate ignition, cloud density (more or less dense than air), delayed ignition, and the effects on the site. Consideration of the release quantity and duration will affect the resulting atmospheric stability calculation.

Standard equations and methods are available to predict the resulting thermal radiation flux near the hazard source. Gas dispersion is very dependent on wind velocity; in this model the Gaussian plume description is used.

The concentration distributions for two-dimensional spreading are involving instantaneous release are:

$$C(x,y,0,t) = \frac{Q}{(2\pi)^{3/2}\sigma_y\sigma_z\sigma_x} exp\left[-0.5\left(\frac{(x-ut)^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)\right]$$

For continuous release they are:

$$C(x,y,h) = \frac{Q}{2\pi\sigma_y\sigma_z u} exp\left[-0.5\left(\frac{y^2}{\sigma_y^2}+\frac{h^2}{\sigma_z^2}\right)\right]$$

where x is the distance away from the source down wind, m; u is the wind velocity, m/s; t is time, sec; $\boldsymbol{h}$ is plume height, m.; Q is mass release (kg for instantaneous release, kg/s for continuous release); **HHV/LHV** is the high and low heating value, Btu/mole; σ_I are the dispersion parameters for the x, y, z directions, which depend on atmospheric stability.

Methodology

Basic Information

In this hypothetical case, natural gas is delivered from the source to the platform by a pipeline with an inside diameter of 24 inches × 0.562" W.T. × API 5L Grade X65 and is approximately 48 km length. The temperature of the natural gas inside the pipeline is 120°F at a constant pressure of 2,000 psig. The pipe is assumed to bet equipped with block valves at various intervals in the model below (25 1,000 2,000 and 3,000 m from the leak).

The gas composition is described in ***Table 1*** using data provided by Petroleum Authority of Thailand." The submarine pipeline traverses a section of the Central Gulf of Thailand at 60±5 m water depth and is connected via expansion loops and risers with the platform. The pipeline system includes both sub-sea and over-sea components (on treatment units over the platform). The leakage could occur on the vessel walls, around the connection (flange, reducer, enlarger, control-detector, valves, etc.), welding, or manhole. They are then classified into two categories: 20% and 100% of pipe diameter leakage for the best and the worst case, respectively. ***Table 2*** summarizes the various possibilities of leakage.

Table 1
Chemical composition and physical properties of natural gas

Compositions and conditions	
N_2 / CO_2	1.42 / 23.00
C_1	67.51
C_2	4.63
C_3	2.00
n-C_4	0.48
i-C_4	0.39
n-C_5	0.16
i-C_5	0.11
C6-C9	0.30
MW	24.6
SG	0.85
HHV / LHV, Btu	870 / 787

Table 2
Percent consideration for several leakages

	% pipe diameter
vessel	100
flange and weld	20 and 100
reducer and enlarger	20 and 100
temperature and pressure well	20
valve	20 and 100

Computer Program

A computational procedure was written using Excel 7.0 spread sheets to implement the algorithms described above. They provide the concentration profiles and resulting energies for both the continuous and instantaneous release.

Results and Discussions

Using the input parameters of inside diameter, temperature and pressure of natural gas, gas heating value, and molecular weight, it was determined that the natural gas leakage behaves as a critical flow under all conditions. With respect to the use of emergency block valve at different distances from the leak ((25 1,000 2,000 and 3,000 m), in the case of 20% pipe diameter leakage it was determined that release would be instantaneous for 25 m block valve length and continuous for the rest. In all cases of 100% pipe diameter leakage, instantaneous release was predicted (see ***Table 3***).

Table 3
Required time for the leakage

	t_r for 20% pipe dia leakage (sec)	t_r for 100% pipe dia leakage (sec.)
25	3.37	0.13
1000	134.70	5.39
2000	269.50	10.78
3000	404.20	16.17

Using the gas composition from ***Table 1***, LEL and UFL values were determined to be 4.50 and 14.47 %vol, respectively. When gas release concentrations fall within this range, the harmful effects on the surrounding environment by gas ignition and explosion must be considered. These effects are classified as follows:

Instantaneous release

Immediately Ignition

In this case the gas is ignited while it is still escaping from the containment. Immediate ignition can result in a fire ball which can cause damage to the immediate vicinity of a pipeline (but would not affects anything outside a plant boundary). In the case that the heat radiation is sufficiently high, other objects which are flammable can be ignited. ***Table 4*** shows the distance for the amount of heat radiation that can effect. For the worst case (3,000 m. block valve placement), it was found that the distance of about 90 m away from a release source would be relatively safe.

Delayed Ignition

In this case, the material has escaped from the containment and has formed a cloud which is drifting downwind at 3 m/s. The behavior of the cloud drifting would depend on the weather conditions. These are divided into six categories (see below). Delayed ignition can result in an explosion or a flash fire which can cause widespread damage. The calculated concentration distributions are shown in ***Table 5***. It is possible to identify the position and duration of the flash fire or explosion at short time intervals after gas release.

Table 4
Radius and the damages from fireball

Damage Effects	A	B	C	D
100% lethality in 1 min. and 1% lethality in 10 s.	5.79	20.04	25.30	29.00
100% lethality in 1 min. and significant injury in 10 s.	7.09	24.54	30.99	35.52
1% lethality in 1 min. and 1st degree burns in 10 s.	10.03	34.70	43.82	50.23
cause pain if duration is longer than 20 s. but blistering is unlikely.	17.73	61.36	77.47	88.79
Causes no discomfort for long exposure.	28.04	97.01	122.49	140.04

Case A, B, C, D: 25, 1000, 2000, and 3000 m for emergency block valve length

Table 5 illustrates the concentration distributions for the 1,000 m block valve distance and a one-dimensional consideration of wind. It was found that after 2 to 6 sec. after release, a flash fire would occur at a distance of 6 to 15 m. away from the source. Similar results were found for the 2000 m and 3000 m distances, but these conditions resulted in significant effects on the atmospheric stability categories E and F. Even though the flash fire occur, it will persist for only a short period of time.

Continuous Leakage

Immediate Ignition

The results are similar to the instantaneous case, but the phenomenon here resembles a jet flame. The damage effects as a function of distance are presented in ***Table 6***. For the worst case (3,000 m.), it was found that the distance of only 30 m away from the release source would be considered safe. For the continuous release, effects are confined to short distances.

Table 6
Radius (meters) and resulting damages from a jet flame

Damage Effects	B	C	D
100% lethality in 1 min. and 1% lethality in 10 s.	6.70	8.47	9.70
100% lethality in 1 min. and significant injury in 10 s.	8.21	10.37	11.88
1% lethality in 1 min. and 1st degree burns in 10 s.	11.61	14.66	16.81
cause pain if duration is longer than 20 s. but blistering is unlikely.	20.53	25.92	29.71
Causes no discomfort for long exposure.	32.46	40.99	46.98

Case B, C, and D: 1000, 2000, and 3000 m for emergency block valve length

Delayed Ignition

The calculational approach is similar to the case of instantaneous release. The calculations for 1,000 and 2,000 m emergency block valve positions found no impact for any jet flame at distances of more than 40 m from the source. ***Table 7*** shows the results of the concentration distribution as a function of time for the 3,000 m block valve distance in one dimension, downwind (3 m/s wind velocity). The concentrations in Table 7 do not fall in the range of LEL and UEL for this system. The jet flame is unlikely to appear at the site of gas release.

Conclusion

The basic calculational approach described here shows that the concentration distribution of natural gas leakage from the pipeline system (or other facilities) is very important for assessing the impact on the local environment. A range of conditions was considered and the results show significantly different effects. Affected distances ranged from 20-30 meters under conditions of continuous gas release with accompanying fire, to approximately 90 meters in the worst case of instantaneous release and ignition caused by 100% failure.

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