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HUMAN HEALTH RISKS ASSESSMENT DUE TO NATURAL GAS PIPELINES EXPLOSIONS

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ABSTRACT

Natural gas is transported mainly by pipelines throughout the world. Therefore it is necessary to assess and manage the resulting risks regarding human health issues due to gas toxicity and flammability. It is possible to assess the risk of irreversible damage to a human being for any accidental scenario by introducing specific vulnerability functions. Events such as flash fire, vapor cloud explosion, and fire can be understood by the maximum predicted amount of vapor within the flammability limits for the entire history of its dispersion. Another danger to human health lies in the flammability of natural gas transportation systems. A human health risk assessment study in the event of such an accident has been carried out in this paper. In this study, a 1 to 20% accidental rate is considered for assessing individual risk due to flammability. A newly developed flammability risk management model is used in the present study. The research shows that the individual risk due to the flammability of natural gas is not more than an 18 percent human health hazard. The findings of this study will be helpful to improve health hazard risk management and remediation.

Keywords: Human health; natural gas pipelines; flammability limit; individual risk.

1. INTRODUCTION

Risk assessment addresses pipeline safety, environmental protection, financial management, project or product development, and many other areas of business performance. In this case, risk assessment considers pipeline safety in relation to protecting human life, the environment and property due to pipeline failure accidents. A pipeline can fail and release oil

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or natural gas into the environment and may cause many problems including environmental degradation, and loss of human life due to flammability and damaging effects of pollution as well.

The goal of risk assessment is to assess the likelihood that a possible threat could lead to a failure at a particular location on the pipeline and what the consequences might be. This assessment is conducted by identifying the specific characteristics of the pipeline at any given location, along with the unique characteristics of the area around the pipeline. The susceptibility of the pipeline to failure and its impacts is dependent on numerous characteristics, such as the type and condition of the pipe's coating, condition of the soil around the pipe, distance of pipeline from locality, and the contents of pipeline. For instance, water content of gas in pipes usually is one of the biggest reasons of corrosion in presence of other active components (Knickerbocker, 2006).

To determine the individual risk of an explosion hazard, flammability limits data are essential in a natural gas pipeline. Flammability limits are commonly used indices to represent the flammability characteristics of gases. The flammability limit criterion, and other related parameters have been broadly discussed in the available literature (Vanderstraeten et al., 1997; Kenneth et al., 2000; Kevin et al., 2000; Pfahi et al., 2000; Wierzba and Ale, 2000; Mishra and Rahman, 2003; Takahashi et al., 2003; Liao et al., 2005a; Liao et al., 2005b).

Hossain et al. (2008) studied the flammability and individual risk assessment for natural gas pipelines. They developed a comprehensive model for the individual risk assessment where the flammability limit with existing individual risk for an accidental scenario has been combined. Their model applies to the major accidental area within a locality surrounded by pipelines, and for any natural gas pipeline risk assessment scenario. Hossain et al. (2008) also verified the model using available field data. However, they assume a 10% accident occurrence due to flammability in a natural gas pipeline accident. The accidental scenario may be any percentage within a limited value. The present study applies the same model to verify different accidental scenarios. For a case study, 1%~20% accidental rates are considered in this paper, a conservative figure in risk assessment.

In the case of risk assessment, Fabbrocino et al. (2005) reported that the assessment must be as conservative as possible. They also added that whatever the final assessment: "worst case" should always be considered. When uncertainties are faced, the deterministic assessment even in the framework of probabilistic safety assessment should be taken into account. This approach is particularly effective, when late or early ignition assumption is considered in risk assessment (Fabbrocino et al., 2005).

The human health risk assessments determine how threatening a pipeline accident will be to human health. The main objective of human health risk assessment is to determine a safe level of contaminants or releases of toxic compounds, such as oil and natural gas from a pipeline. In the case of individual humans, there is a standard at which ill health effects are unlikely. It also estimates current and possible future risks. This paper examines the individual risk of natural gas flammability on human health. The goal of this study is to manage risks to acceptable levels, and recommend a method for risk managers to incorporate risk assessment information for the planning and developing of pipeline networks.

2. Risk Management

Pipeline risk management deals with pipeline system failures due to:

1) Corrosion.
2) Cracking.
3) Material degradation or defects.
4) Third-party damage such as sabotage.
5) Earth movements.

It is paramount to assess and manage pipeline risks by considering the potential consequences of pipeline failures. The possible potential consequences are:

1) Damage to human health and safety including injuries and fatalities.
2) Property damage.
3) Environmental damage.

Long-term exposure to hazardous material is the paramount risk regarding long-term damage to human health such as asthma and cancer. Safety risk is the acute risk related to short-term damage to the human body such as burns, injuries, and death due to an accident or exposure to explosion.

Risk management is the process that examines the following phases (see Figure 1):

1) Identification.
2) Assessment.
3) Remediation.
4) Evaluation.
5) Maintenance.

Risk identification deals with:

1) Site location.
2) Hazard identification.
3) Risk analysis.

Risk assessment involves estimating various health and safety risk parameters such as the individual risk. There are two types of risk assessment:

1) Qualitative.
2) Quantitative.

The risk remediation stage addresses the following steps:

1) Strategy proposal.
2) Strategy implementation.

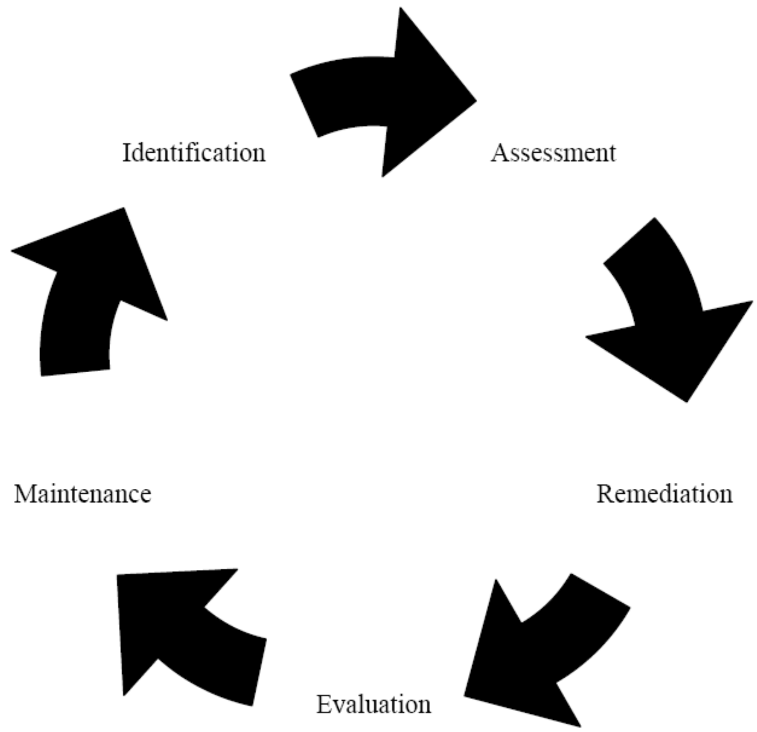

Figure 1. Risk management for natural gas pipelines.

3. Human Health Risk Assessment

The components of human health risk assessments are: planning and scoping, exposure assessment, acute hazards, toxicity and risk characterization. The main components of human health risk assessment are shown in Figure 2. There are four different steps in assessing human health risk, which are Planning and Scoping, Exposure Assessment, Acute Hazard Assessment, and Risk Characterization. For efficient risk assessments the 'planning and scoping' of the information and data are needed. It should be done before the field investigations and site characterization.

The second step of human health risk assessment is 'exposure assessment' (see Figure 2) that is the contact of natural gas to the human. This process considers how much time, duration and frequencies of the chemical contact with a human in the past, present and future. The 'exposure assessment' step should be done following step one. This step should be conducted just once, but if necessary it can be repeated for accuracy of the assessment. "In the case of human risk assessment, 'acute hazards' mean the conditions that create the potential for injury or damage to occur due to an instantaneous or short duration exposure to the effects of an accidental release. In this study, it is mainly the flammability of natural gas.

'Hazard identification' is the process of determining whether exposure to the natural gas can cause an increase in the incidence of a particular adverse health effect. Generally, it is done by the dose responses of particular chemicals. However, this study considered the flammability. The 'Risk Characterization' process is the synthesis of results of all other steps and the determination how dangerous the accident is to pipelines. It also considered the major assumptions, and scientific judgments. Finally, the risk characterization estimates the uncertainties embodied in the assessment.

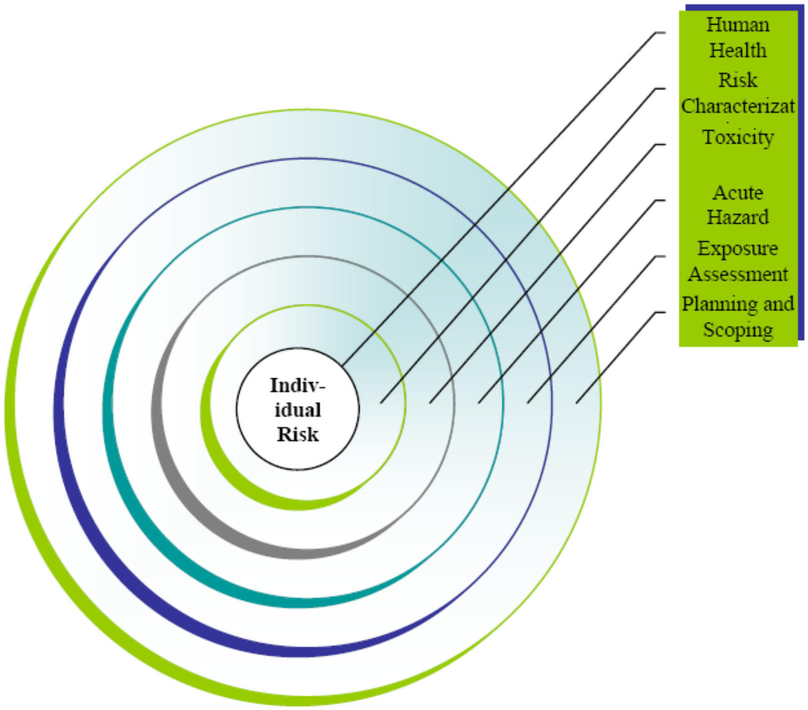

Figure 2. Different components of human health risks assessment.

3.1. Human Health Risk Levels

In the risk assessment, human health is the major concerning issue, but there are other factors to consider as well, such as ecological risk assessment. Pipelines carry natural gas which has numerous toxic compounds that might directly and indirectly cause risks to human health. Pipelines carry natural gas that contains methane, ethane, propane, iso – butane, normal – butane, iso – pentane, normal – pentane, hexanes plus, nitrogen, carbon dioxide, oxygen, hydrogen, hydrogen sulfide. Sour gas contains larger amount of hydrogen sulfide. In the case of any pipeline accident all of these compounds are released. Due to flammability and exposure of all of these compounds, different levels of risk can take place. Very recently (May 2006), more than 150 people were killed due to flammability in case of pipelines. It is reported that a ruptured fuel pipeline exploded and caught fire near Nigeria's largest city, Lagos (IRIN, 2006). This pipeline transports fuel from a depot at the Lagos port for domestic use inland. Victims were inhabitants of poor fishing villages. Pipeline accidents are common in third world counties, such as Nigeria, oil rich African nation. In 1998, it is reported that more than 1000 people died due to a flammability accident in Jesse, near the oil town of Warri, Niger Delta (IRIN, 2006).

In above accident report, it is revealed that due to strong flammability the fate is certainly death, but exposures to other components, such as hydrogen sulfide have different risk levels.

In Table 1, different risk levels cause by the hydrogen sulfide is shown. This phenomenon needs to be considered seriously in case of sour gas, where hydrogen sulfide concentration is higher. Generally, the typical sulphur content is 5.5 mg/m^3, which includes the 4.9 mg/m^3 of sulphur in the odorant (mercaptan) added to gas for safety reasons.

Table 1. Human health risk levels

Risk levels	Concentration (ppm)	Effects
Negligible or no- Risk	0.01-0.3	Odor threshold (highly variable)
Minimal Risk	1-5	Moderate offensive odor, may be associated with nausea, tearing of the eyes, headaches or loss of sleep with prolonged exposure; healthy young male subjects experience no decline in maximal physical work capacity
Slightly Moderate Risk	10 - 8 h	Occupational exposure limit
Moderate Risk	20-50	Ceiling occupational exposure limit and community evacuation level, odor very strong
Risk	100	Eye and lung irritation; olfactory paralysis, odor disappears
High Risk	150-200	Sense of smell paralyzed; severe eye and lung irritation
Severe Risk	250-500	Pulmonary edema may occur, especially if prolonged
Extremely High	500	Serious damage to eyes within 30 min; severe lung irritation; unconsciousness and death within 4-8 h; amnesia for period of exposure; "knockdown"
Critical Level	1000	Breathing may stop within one or two breaths; immediate collapse

Source: Guidotti, 1994.

3.2. Combustion Properties of Natural Gas

As mentioned earlier, natural gas has an extreme risk of flammability due to its composition. To understand the flammability risk of natural gas, the combustion properties of natural gas are presented in Table 2 (Data source: Union Gas, 2006). It is noted that the combustion properties of gas depends on its compositions, but a general estimations is shown in Table 2. The properties shown are an overall average on the Union Gas system (Union Gas, 2006).

Table 2. Typical Combustion properties of Natural Gas

Ignition Point	593 ºC
Flammability Limits	4% - 16% (vol. % in air)
Theoretical Flame Temperature (stoichiometric air/fuel ratio)	1960 ºC (3562 ºF)
Maximum Flame Velocity	0.3 m/s
Relative density (specific gravity)	0.585

4. INDIVIDUAL RISK BASED ON FLAMMABILITY

Hossain et al. (2008) have shown the concept of individual risk due to flammability at a locality where dense populations live in. Figure 3 has been redrawn from this reference where detailed analysis has been presented. An accident due to flammability is considered here as the main cause of the incident. In Figure 3, OB is the maximum distance covered by the fire flame within which a fatality or injury can take place. BA and BC are the maximum distances traveled by the flame.

The individual risk (IR_f) due to flammability limit in a natural pipeline can be written as:

$$IR_f = \sum_i \frac{\varphi_i}{100} \int_{-l}^{+l} \int_0^{h_{\max}} (UFL_i - LFL_i) dhdl \tag{1}$$

and the total individual risk can be written as;

$$IR_T = IR + IR_f \tag{2}$$

where,

φ_i = The failure rate per unit length of the pipeline associated with the accident scenario *i* due to flammability

l = Pipeline length, *ft*

UFL, LFL = Upper and lower flammability limit

$l_{\pm}$ = Ends of the interacting section of the pipeline in which an accident poses hazard to the specified location, *ft*

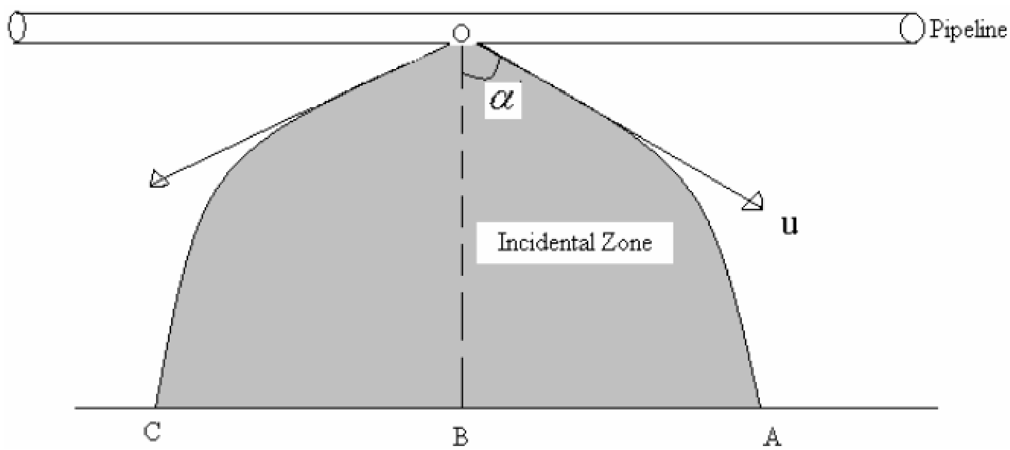

Figure 3. The relation of variables related with IRf (redrawn from Hossain et al., 2008).

Table 3 shows the different data for number of fatalities/injuries and number of fatalities/injuries due to natural gas flammability accident in pipeline from 1985 to 2005. The data has been collected from the department of pipeline safety of U.S.A.

Table 3. Number of injury and flammability data for different percentage (Data Source: Website 1)

Fatality/ Injury	Fatality/injury due to natural gas flammability									
	1%	3%	6%	8%	10%	12%	14%	16%	18%	20%
97	0.97	2.91	5.82	7.76	9.7	11.64	13.58	15.52	17.46	19.4
102	1.02	3.06	6.12	8.16	10.2	12.24	14.28	16.32	18.36	20.4
103	1.03	3.09	6.18	8.24	10.3	12.36	14.42	16.48	18.54	20.6
109	1.09	3.27	6.54	8.72	10.9	13.08	15.26	17.44	19.62	21.8
110	1.1	3.3	6.6	8.8	11	13.2	15.4	17.6	19.8	22
118	1.18	3.54	7.08	9.44	11.8	14.16	16.52	18.88	21.24	23.6
121	1.21	3.63	7.26	9.68	12.1	14.52	16.94	19.36	21.78	24.2
124	1.24	3.72	7.44	9.92	12.4	14.88	17.36	19.84	22.32	24.8
137	1.37	4.11	8.22	10.96	13.7	16.44	19.18	21.92	24.66	27.4
141	1.41	4.23	8.46	11.28	14.1	16.92	19.74	22.56	25.38	28.2
142	1.42	4.26	8.52	11.36	14.2	17.04	19.88	22.72	25.56	28.4
146	1.46	4.38	8.76	11.68	14.6	17.52	20.44	23.36	26.28	29.2
154	1.54	4.62	9.24	12.32	15.4	18.48	21.56	24.64	27.72	30.8
162	1.62	4.86	9.72	12.96	16.2	19.44	22.68	25.92	29.16	32.4
163	1.63	4.89	9.78	13.04	16.3	19.56	22.82	26.08	29.34	32.6
172	1.72	5.16	10.32	13.76	17.2	20.64	24.08	27.52	30.96	34.4
177	1.77	5.31	10.62	14.16	17.7	21.24	24.78	28.32	31.86	35.4
201	2.01	6.03	12.06	16.08	20.1	24.12	28.14	32.16	36.18	40.2

Figure 4 has been generated using the data shown in Table 3. It shows the number of incidents with individual risk due to flammability for different percentage of flammability risk at pipeline. The data has been collected from the U.S. office of pipeline safety, incident summary statistics from 1986 to August, 2005 (Web site 1).

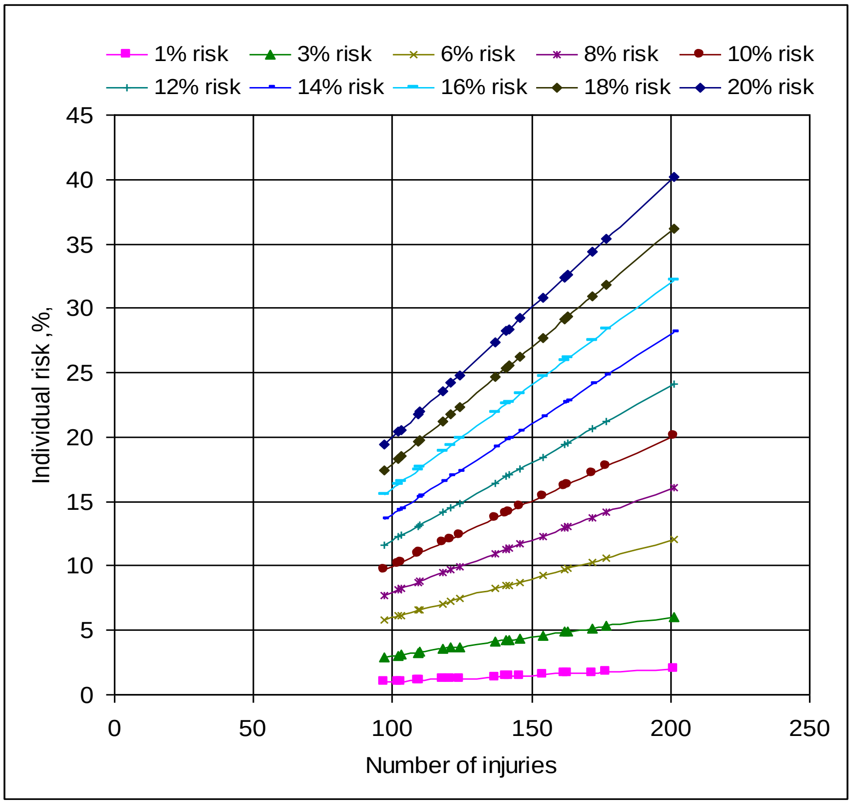

Figure 4. Individual risk due to flammability with number of injuries.

In this figure, the individual risk is increasing to a steeper trend when human health hazard risk due to flammability injuries are increased. It means that the individual risk factor is very much influenced by the flammability risk factor within the contour locality.

At present, there are many models available to investigate individual risk (John et al., 2001; Jo et al., 2002 and 2005; Fabbrocino et al., 2005). However, there is no model available that handles both flammability limit and lethality for measuring individual risk for human health hazard. It is difficult to get data for the accidental scenario due to flammability. Based on available information and data dealing with this issue, the Hossain et al., (2008) model can be easily used to verify with any sets of data with confidence. In this study, 1~20% of accidental scenarios are considered to be due to flammability (web site 1). Using these data, the model (Equation 1) is tested and results are shown in Figures 5 and 6. Here it has been assumed that the *UFL* and *LFL* are 15.6 and 5.0 for the calculation. $q_{\min}$ is considered as $1\, ft^3/\sec$, $\alpha = 45°$, t = 1 min and $d_{hole} = 0.5$ ft for a case study. Jo and Ahn (2002) showed that the maximum value of h was 66 *ft* and l was 99 *ft*. They used the triangular explosion concepts. Here the calculation shows that h is 80.5 ft and l is 129.93 ft (Hossain et al., 2008). These values seem to be quite reasonable since the projectile explosion model proposed in the previous paper is more precise and convenient.

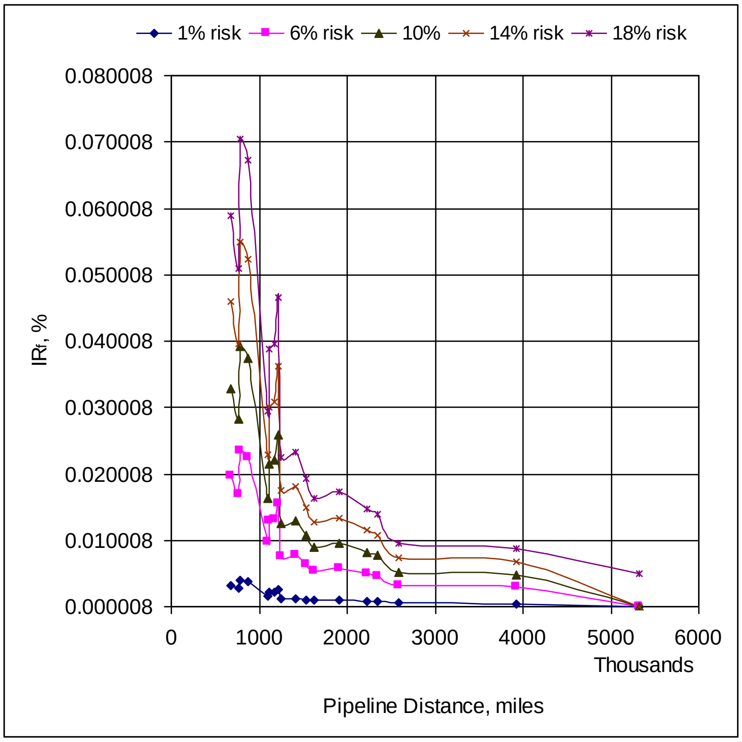

Figure 5. Individual risk due to flammability as a function of pipeline distance.

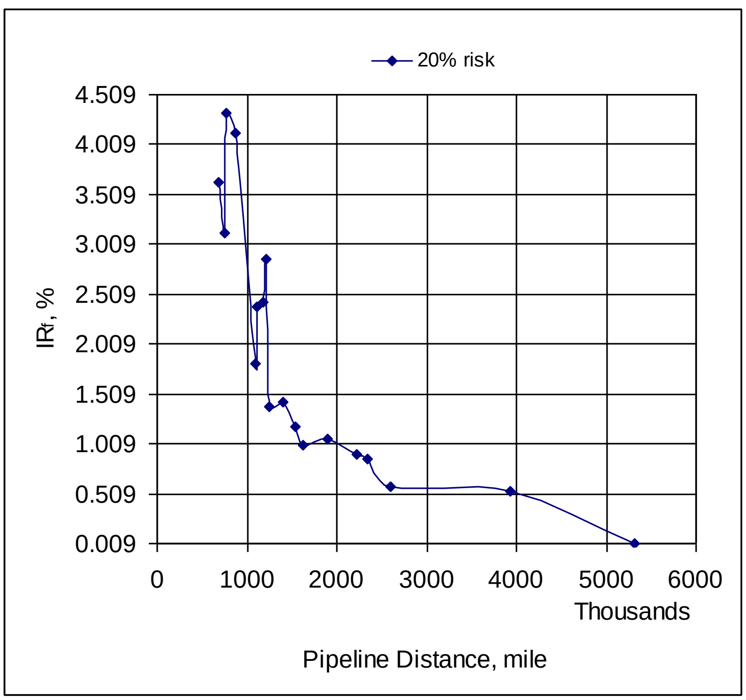

Figure 6. Individual risk due to flammability as a function of pipeline distance.

Table 4 shows the different individual risk due to flammability data for different pipeline distances. The flammability data has been calculated using equation (1). The pipeline data that causes the fatalities/injuries to natural gas in pipeline accidents are from 1985 to 2005. The data has been collected from the department of pipeline safety of USA.

Table 4. Individual risk due to flammability with pipeline distance

Pipeline distance, (miles)	Individual risk due to flammability					
	1.0%	6.0%	10.0%	14.0%	18.0%	20.0%
5320616	8.72E-06	2.33E-05	3.49E-05	4.65E-05	0.005078	0.009638
3928390	0.00048742	0.002927	0.004879	0.00683	0.008781	0.538715
2591365	0.0005272	0.003163	0.005272	0.00738	0.009489	0.582692
2339883	0.00077257	0.004634	0.007723	0.010812	0.013901	0.853882
2229440	0.00081789	0.004908	0.00818	0.011452	0.014724	0.903967
1905511	0.00095825	0.005749	0.009582	0.013415	0.017248	1.059106
1625284	0.0009052	0.005431	0.009051	0.012672	0.016292	1.000471
1534665	0.00107209	0.00643	0.010716	0.015003	0.01929	1.184929
1407148	0.00129314	0.007748	0.012913	0.018078	0.023243	1.429245
1249316	0.00124893	0.007484	0.012474	0.017464	0.022453	1.380382
1213143	0.00258628	0.015525	0.025874	0.036224	0.046574	2.858489
1173612	0.00219945	0.0132	0.021999	0.030799	0.039599	2.430938
1107880	0.00215524	0.012905	0.021509	0.030112	0.038716	2.382075
1095067	0.00163577	0.00981	0.016351	0.022891	0.029431	1.807933
867581	0.00373574	0.022426	0.037377	0.052328	0.067279	4.128928
776574	0.00391258	0.0235	0.039167	0.054834	0.070501	4.324381
759404	0.00282944	0.017002	0.028337	0.039672	0.051006	3.127236
677750	0.00328259	0.019667	0.032778	0.04589	0.059001	3.628082

It shows the individual risk due to flammability with pipeline distance. The normal trend of the curve decreases with the increase of pipeline distance which leads to a separate scenario of accidents due to flammability. This chart also shows the impact of flammability on an accidental scenario. The interesting outcome of this model shows that human health hazard risk due to flammability in individual risk assessment of natural gas is limited by 18% of the total risk factor (see Figures 5 and 6). These figures have been generated using the data shown in Table 4. Beyond 18% of total individual risk, the figures do not fit with the other percentages of risk and the values of these calculations are not realistic (see Figure 6). This information simply means that the human health hazard individual risk due to flammability of natural gas does not go beyond 18% of individual risk.

CONCLUSIONS

Extensive pipeline networks for natural gas supply systems possess many risks. Appropriate risk management should be followed to ensure safe natural gas pipelines. Individual risk is one of the important elements for quantitative risk assessment. Considering the limitations in conventional risk assessment, a novel method is developed for measuring individual risk combining all probable scenarios and parameters associated with practical situations taking into account gas flammability. These parameters can be calculated directly by using the pipeline geographical and historical data. By using the proposed method, the risk management can be more appealing from practical point of view. The proposed model is found to be innovative using pipeline and incident statistical data. The method can be applied to pipeline management during the planning, design, and construction stages. It may also be employed for maintenance and modification of a pipeline network.

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