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# Hazard analysis of failure of natural gas and petroleum gas pipelines

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ABSTRACT

This paper deals with the analysis of hazards associated with accidental release of high pressure from gas-pipeline transportation system. Simplified equations which are related to the fluid properties, operating pressure, the diameter of pipeline, hole or rupture diameter and the length of the pipeline have been used for the hazard analysis due to pipeline failure. The kind of release (i.e. leak) through a hole or the complete rupture was found not to affect the effective release rate because of an increase in the operating pressure. Among various gases, the release rate of butane with lower value of specific heat ratio ($\gamma$) is found to be always higher than that of propane and methane which have higher value of $\gamma$. Decay coefficient, defined as the ratio of release rate at any instant and to the initial maximum release rate, decreases with an increase in the leak (or hole) size. The accident affected distance increases with an increase in the hole size. During the leakage of natural gas and petroleum gas pipeline, affected distance of hazard is slightly higher for fire as compared to other events. The simplified models can be used with confidence to estimate the hazard distance or hazard area. The procedure developed will be helpful for safety management or emergency response planning for the pipeline transportation of the natural gas and petroleum gas.



## 1. Introduction

Energy is one of the essentials for life sustenance on the earth. Fossil fuels like coal and various gaseous and liquid fuels derived from natural gas and petroleum crude oil processing have been used for long. Liquid petroleum gases (LPG) and natural gas (NG) have also been used as commercial and domestic fuel in India. The wide acceptability of NG/(compressed natural gas (CNG)) and PG as a fuel source is because of the ease of their bulk transportation (through pressurized road/rail/ship tankers/containers, and cylinders, and pipelines), ease of distribution at low pressures and comparatively cleaner combustion characteristics than solid/liquid fuels.

The safety of NG and PG pipelines is very crucial for meeting the supply chain and demand requirements. Since the natural gas derived PG and the PG from crude oil processing have different characteristics, particularly the composition of unsaturated compounds (e.g. olefins), the vapour pressure and density, the safety requirements may also vary a little. There have been a number of leakages from NG and PG pipelines, leading to fire and explosion and the consequent loss of properties and injuries to humans (Cheng et al., 2015). The recent NG pipeline leakage accident in West Virginia and at other places point to the fact that the NG and PG leakages from pipelines may becomes catastrophic, unless suitable and proper precautionary measures are taken for its prevention and release mitigation.

Montiel et al. (1997) have reported that out of 185 accidents involving natural gas, the pipeline accidents accounted for 127, and the most frequent accidents were caused by mechanical failure of the pipelines. The available European failure data reveal the pipeline failure rate of $2.1 \times 10^{-4}$ (for small diameter pipes) to $7.1 \times 10^{-4}$ (for large diameter pipes) per km per year. These failure rates are much higher than the standard acceptable pipeline failure probability which is taken as $10^{-6}$ per km per year (Taylor, 1994). Even these rates are much lower than the $6.25 \times 10^{-2}$ as the estimated pipeline failure probability through fault tree analysis (FTA) (Yuhua and Datao, 2005; Glickman and Erkut, 2007). It is, therefore, essential that the pipeline accidents are analyzed and the consequences of the accidents are assessed.

If there is an accidental leak from a pipeline transporting NG/PG, it may lead to fires and/or explosions impacting adversely the human habitat, property and the environment. Therefore, one has to estimate the release rate of the gas from the pipeline due to its

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failure. The gas release may be from a small diameter (size) leak, from a hole (of size, $d_o$) in the pipeline or the high volume discharge from the pipe-rupture. It has been suggested that a very small pin hole/crack of size (diameter) ≤20 mm may lead to a 'leak'; slow release may result from pipeline holes of size 20 mm $\le d_o \le d$; and a rupture may have a diameter of the hole larger than the pipeline diameter, $d$ (EGIG, 1970–2007). Therefore, it is essential to estimate the gas release rate from the pipeline failure for the case of continuous and constant flow rate, and the decreasing flow rate in case of emergency shutdown of the compressor or the valve. It is also necessary to estimate the area of hazard associated with the habitat, property and environment which will depend on the type of the pipeline failure and associated gas release, the time period of release, ignition time, meteorology and the topography of the area.

In India several incidents of NG pipeline failure have been reported which resulted in the loss of people, environment and property. Although, a number of researchers have carried out quantitative risk assessment (QRA) of gas transportation pipeline (Joel and Ducan, 2003; Muhlbauer, 2004; Metropolo and Brown, 2004; Jo and Ahn, 2005; Sklavounos and Rigas, 2006; Jo and Crowl, 2008; Liu and Liu, 2009; Jafee et al., 2009), a detailed assessment of damage from the varying gas release rates from a leak (crack or puncture), a hole or a complete rupture has not been presented so far.

The pipeline of PG/NG or other hydrocarbon materials may experience fatigue, creep, brittle fracture, and corrosion, with age and usage, and other failures caused by natural disasters (Yuhua and Datao, 2005). The case studies of pipelines provide clear understanding of the risks involved in NG/PG/CNG transport and help in making suitable safety standards regarding hazards zonation and related risks.

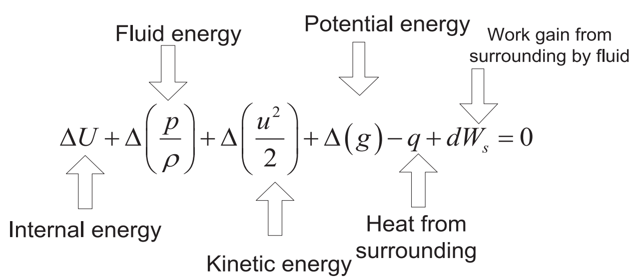
This paper aims at providing a simplified mathematical model for the assessment of the release rate of NG and PG by the sudden release of the gas from the highly pressurized pipelines. It is also aimed to estimate the hazard distance from the failure point due to thermal radiation and explosion caused by the release of the gas due to leak or the complete rupture of the highly pressurized pipeline of NG and PG. For assessing and calculating the surrounding area of concern and the distance from the leak site of a pipeline, one has to evaluate (i) the release rate of the gas through the crack/hole in a highly pressurized pipeline, (ii) the thermal radiation hazard from the release rate of the gas, and (iii) the overpressure generated from the cloud explosion and the hazards from the overpressure.

## 2. Mathematical model

The fluid flow through pipelines may be isothermal, non-isothermal and adiabatic process depending upon the state of the fluid, the flow condition, climatic condition of the area through which pipeline is passing, state of insulation, if any, etc. Long distance pipeline liquid transport of such materials as pentane, naphtha, etc., may be assumed to be the isothermal process as the fluid flows through uninsulated pipelines. Short distances pipeline gas transport of such fuels like PG, NG, etc. under pressure are generally considered to be non-isothermal or adiabatic as these fuels flow through insulated pipelines (Cochran, 1996). The gas transport through pipelines is considered as compressible fluid flow. Therefore, the analysis of pipeline transport of gases under pressure involves several governing equations such as the state, continuity, momentum and energy equations. The governing equations are as follows:

$$P = \frac{\rho ZRT}{M} \tag{1}$$

Energy balance




$$\Delta U + \Delta\left(\frac{p}{\rho}\right) + \Delta\left(\frac{u^2}{2}\right) + \Delta(g) - q + dW_s = 0 \tag{2}$$

For a differential section of the pipe, the mechanical and the total energy balance equations can be written as follows:

$$\frac{dp}{\rho} + udu + gdz + \Delta\left(\sum F\right) + dW_s = 0 \tag{3}$$

Assuming no shaft or mechanical work done by the system, a negligible change of elevation during the fluid flow and a constant friction loss during the leak, Eq. (3) can be written as

$$\frac{dp}{\rho} + udu + \Delta\left(\sum F\right) = 0 \tag{4}$$

or

$$\int \frac{dp}{\rho} + \Delta\left(\frac{u^2}{2}\right) + \Delta\left(\sum F\right) = 0 \tag{5}$$

where, $p$ is the pressure of the fluid, $\rho$ is the density, u is the velocity, and $F$ is the friction energy. The pressure and frictional losses due to leakage could be given in terms of a discharge coefficient, which may be assumed to be fairly constant over the leak flow range. Thus, the Eq. (5) could be reduced to

$$C_0^2 \int_{P_0}^{P} \frac{dp}{\rho} + \left(\frac{u^2}{2}\right) = 0 \tag{6}$$

For isentropic expansion of an ideal gas, we have:

$$PV^{\gamma} = \frac{P}{\rho^{\gamma}} = \text{Constant} \tag{7}$$

Or