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Calculation of Safety Setback (Rs) For High Pressure Natural Gas Pipeline (Hazard Distances)

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حساب مسافة التراجع الآمن *(Rs)* لخط أنابيب الغاز الطبيعي عالي الضغط (مسافات الخطر)

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Abstract:
This study aims to analyze the required safety setback distance around high-pressure natural gas pipelines and assess the associated hazards. These pipelines run through Misurata City, supplying natural gas to the iron and steel company. The research focuses on essential safety regulations that companies must adhere to, considering the influence of pipeline diameter and internal operating pressure. Additionally, the study examines the role of safety valves in reducing internal pressure and mitigating potential risks. It defines critical safety distances, indicating that exceeding a specific radius (Rs) ensures safety, whereas certain hazardous zones require restricted access, with firefighters supported by water pumps for emergency response. Based on the findings, the study recommends increasing the minimum safety setback from 100 meters to 370 meters and raising public awareness about the potential dangers for residents living near these gas pipelines.

Keywords: Safety Setback, High Pressure, Gas Pipeline, Hazard Distance, High Radiation.

الملخص
تهدف هذه الدراسة إلى تحليل المسافة الآمنة المطلوبة حول خطوط أنابيب الغاز الطبيعي ذات الضغط العالي وتقييم المخاطر المرتبطة بها. تمر هذه الخطوط عبر مدينة مصراتة، حيث تزود شركة الحديد والصلب بالغاز الطبيعي. يركز البحث على اللوائح الأمنية الأساسية التي يجب أن تلتزم بها الشركات، مع الأخذ في الاعتبار تأثير قطر الأنابيب وضغط التشغيل الداخلي. بالإضافة إلى ذلك، تفحص الدراسة دور صمامات الأمان في تقليل الضغط الداخلي والتخفيف من المخاطر المحتملة. كما تحدد الدراسة المسافات الحرجة للسلامة، مشيرة إلى أن تجاوز نصف القطر المحدد (Rs) يضمن الأمان، في حين تتطلب بعض المناطق الخطرة تقييد الوصول إليها، مع دعم رجال الإطفاء بمضخات المياه للاستجابة لحالات الطوارئ. وبناءً على النتائج، توصي الدراسة بزيادة الحد الأدنى للمسافة الآمنة من 100 متر إلى 370 مترًا، بالإضافة إلى تعزيز الوعي العام بالمخاطر المحتملة لسكان المناطق القريبة من هذه الأنابيب.

الكلمات المفتاحية: المسافة الآمنة، الضغط العالي، أنابيب الغاز، مسافة الخطر، الإشعاع العالي.

Introduction

This study examines the pipeline at the Misurata–Libya contract block site No. 035, focusing on two key points: a distribution point receiving gas from Marsa El Brega, 600 kilometers east of Misurata, and the Mellitah oil and gas station, 350 kilometers west of Misurata. It also considers a low-pressure gas station supplying an iron and steel company. The pipeline has a diameter of 0.856 meters, an operating pressure of 480 Psi, a length of 18 kilometers, a maximum operating pressure of 823 Psi, and one valve. Figure 1 illustrates Libya's oil and gas infrastructure [1].

High-pressure natural gas pipelines are intended to run at a maximum pressure that results in a hoop stress of approximately 33% of the pipe material's yield strength. Reducing operating pressure increases safety but is limited by material and operational costs. Another safety measure is maintaining a setback distance from the pipeline centerline to prevent construction in the vicinity. Pipeline routes should also avoid areas where large groups of people gather.

Most large high-pressure natural gas pipelines are subterranean. The earth cover shields the pipe and its coating from UV rays, external impact, thermal stress, and frost heaves. However, there are still considerable issues about long-term corrosion, coating, and impact damage from excavation equipment such as backhoes. Despite their best efforts, operators of backhoes and similar mechanical equipment frequently cause damage to other services throughout the winter, particularly when snow is piled high. The initial damage could be a little scratch in the pipe's anticorrosion coating. However, after a few years, corrosion at that scratch can cause an unanticipated full bore pipe rupture [2].

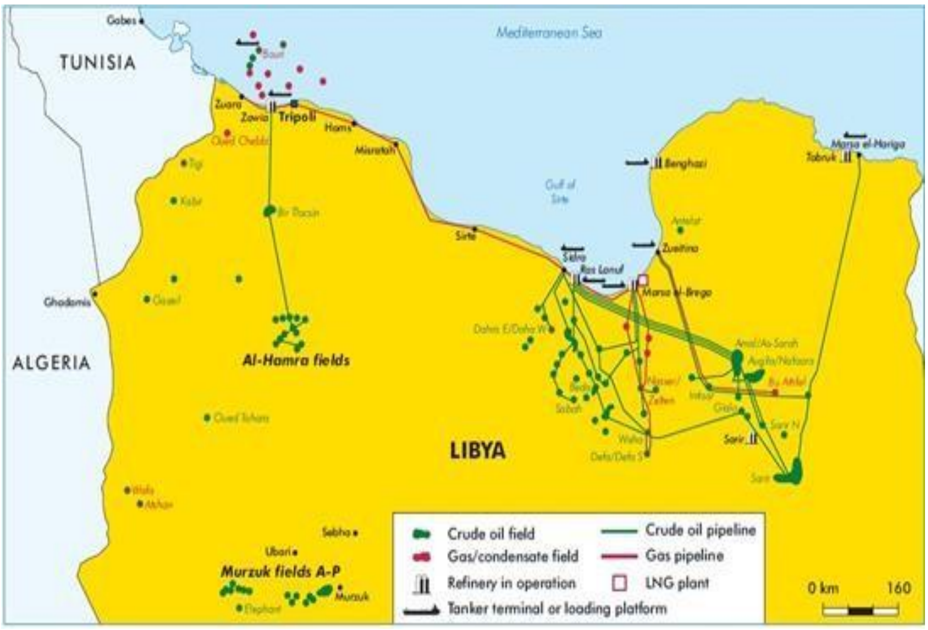


Figure 1: Shows Spreading Map of Libyan Oil And Gas Pipeline And Other Facilities of Energy Resource International Energy Agency [1].

1.1 Pipeline Safety Requirements And Populated Areas:

Work Permits:

The first safety procedure every company must follow is protecting its workers by implementing specific guidelines before they start their tasks, known as work permits.

1.2 Pipeline Safety Requirements for Design and Construction:

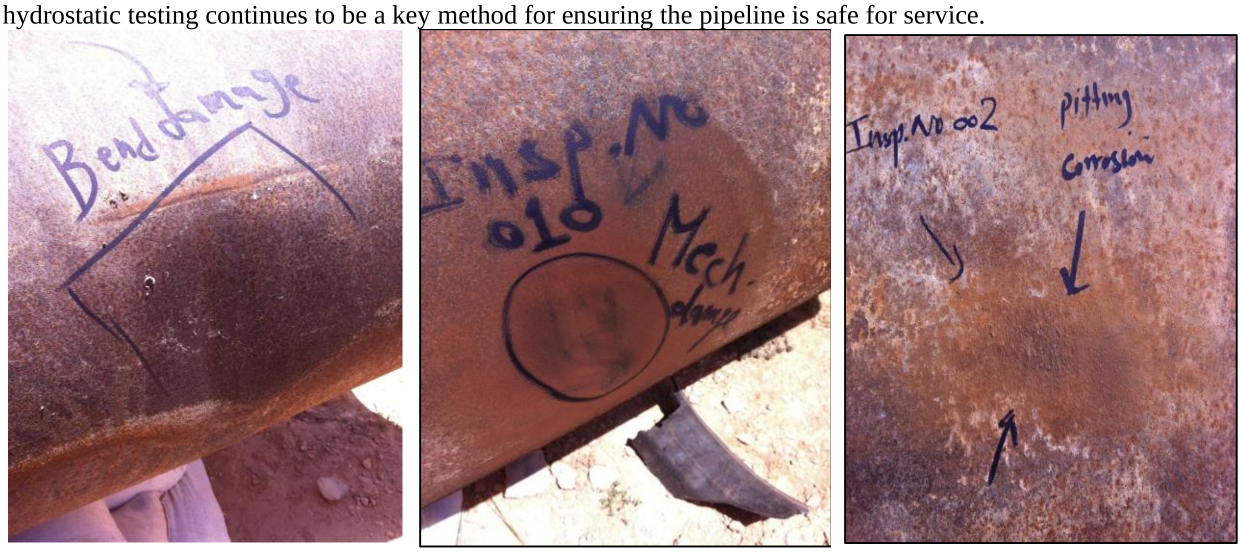
For landowners, one of the most effective strategies to protect their interests is to familiarize themselves with pipeline infrastructure, the specifics of their pipeline easement agreement, the methods to identify potential issues, and the appropriate contacts to address any concerns. The building stage of pipeline installation is a crucial period in ensuring the pipeline's long-term safety and integrity. This section discusses several key issues encountered during the construction phase that are critical to pipeline safety. While many of the safety measures discussed are applicable to gas transmission and regulated gathering pipelines, certain gathering and production pipelines may not be subject to these same standards [3].

Several key safety considerations during the pipeline construction process include:

- Selection of pipeline material
- Depth and placement of the pipeline
- Welding techniques for steel pipelines
- Pipeline coating methods
- Lowering and backfilling procedures
- Valve monitoring and placement
- Monitoring of operating pressure
- Operational testing procedures
- Smart pipeline inspection gauge (pig) technology

In most cases, newly constructed transmission pipelines are required to undergo hydrostatic testing prior to being placed into service. Hydrostatic testing is filling the pipeline with water and pressurizing it to a level that exceeds the intended operating pressure. This test is intended to detect and correct any flaws that may jeopardize the pipeline's ability to withstand its maximum operational pressure. The pressure level applied during hydrostatic testing, Which is often more than **One hundred percent** of the Maximum Allowable Operating Pressure/ MAOP or Maximum Operating Pressure/ MOP, is determined by various factors such as the pipeline's position, category, and design specifications.

The pipeline is designed to resist a specified strength that corresponds to the desired operating pressure. Pipeline failure will come from critical faults that are unable to withstand test pressure. Upon detection of such defects, either the damaged section is repaired, or it is replaced entirely. The testing procedure continues until the pipeline meets the required standards. While hydrostatic testing remains a widely accepted method for detecting defects, alternative technologies, such as Inline Inspection (ILI) tools, are also utilized to identify specific types of imperfections, such as mechanical damage, corrosion, and bending as shown in Figure 2. However, because not all pipelines can be inspected using ILI instruments, and some problems are invisible by ILI technology, hydrostatic testing continues to be a key method for ensuring the pipeline is safe for service.



A. Bending Damage **B.** Mechanical Damage **C.** Pitting Corrosion

Figure 2: Inspection Pipeline [1]

A range of in-line inspection (ILI) devices are designed to detect Specific pipeline faults, such as rust, dents, and gouges. These devices, commonly referred to as "smart pigs," are illustrated in Figure 3.

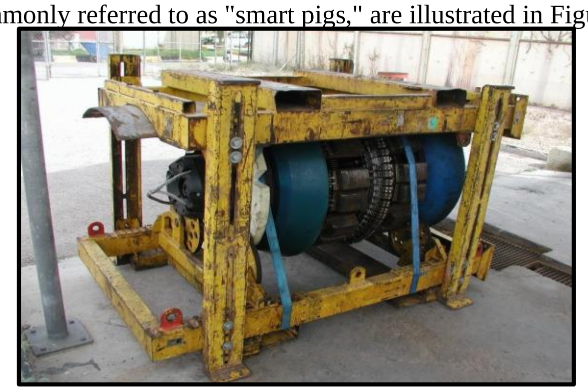


Figure 3: Smart Pig, [1]

1.3 Requirements of the pipeline Safety During Operations

Corrosion Prevention

Steel pipelines; if left unprotected, that means will be surly corroded. Over time; the corrosion can significantly weaken the structural integrity of the pipeline, making it unsafe for operation. However, various technologies have been developed to mitigate corrosion, provided they are properly applied and consistently maintained. The three primary methods for controlling corrosion in pipelines are as follows:

- **Cathodic Protection (CP):**
  Cathodic protection uses direct electrical current to prevent exterior corrosion of a metal conduit. This method is commonly employed when pipelines are buried underground or immersed in water. CP is effective both in preventing corrosion in new pipelines and in arresting the progression of corrosion in existing pipelines [3].
- **Pipeline Coatings and Linings:**
  Coatings and linings are applied to the exterior and, in some cases, the interior of pipelines to serve as a barrier that protects the steel from exposure to corrosive elements [3].
- **Corrosive inhibitors:**
  Corrosion inhibiting substances Corrosion inhibitors are chemical substances added to the interior of a pipeline to reduce the rate at which internal corrosion attacks the steel. This method is particularly important, as cathodic protection does not prevent internal corrosion [3].

1.3.1 Supervisory control and data acquisition/ SCADA systems

SCADA system is a computer-based platform for monitoring and controlling pipeline operations. SCADA systems collect crucial data, including flow rates, operational status, pressure levels, and temperature readings. This information enables pipeline operators to continuously monitor pipeline conditions, respond quickly to operational changes, and address issues such as Equipment problems, failures, and releases. Additionally, many SCADA systems can remotely control various equipment, including compressors, pump stations, and valves, as Figure 4 shows. This functionality enables operators in a control center to change flow rates. and isolate specific sections of the pipeline when necessary. Furthermore, some SCADA systems integrate leak detection mechanisms that assess pressure changes and mass balance, which help identify potential leaks in the pipeline.

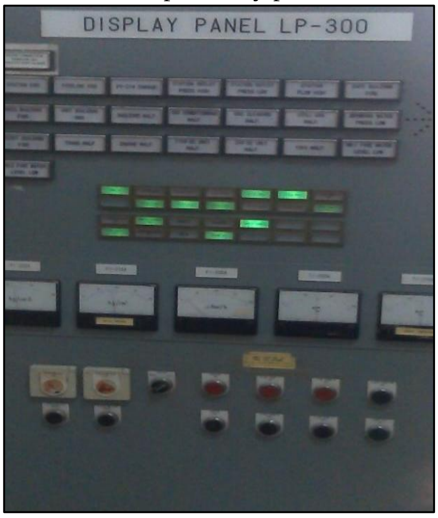


Figure 4: Shows The Scada Panel For Valve At Low Pressure Station [4].

Unfortunately, leak detection systems are not yet capable of identifying all leaks; Pipeline and Hazardous Materials Safety Administration PHMSA data through 2013 shows that only about 11% of hazardous liquid and gas transmission pipeline incidents were initially detected by SCADA or other computerized leak detection [3,4].

1.3.2 Right-of-Way Patrols

Regulations mandate routine inspections of pipeline right-of-ways to detect potential leaks and to ensure that no excavation operations occur inside or near the right-of-way that could jeopardize pipeline safety. For transmission pipelines, these inspections are typically carried out using aerial surveillance; however, federal regulations do not mandate the use of aerial patrols for this purpose.

1.3.3 Leakage Surveys

All natural gas pipelines must be inspected regularly for leaks. During these surveys, workers trace the pipeline path, using specialized gear to detect and assess gas leaks. Although small leaks are common in many gas pipeline systems, their detection is essential for maintaining pipeline safety and preventing larger incidents.

1.3.4 Odorization

All distribution pipelines, as well as natural gas transmission and gathering lines in many cases, must be odorized to aid in the discovery of gas leaks, especially in locations with higher population concentrations. The addition of a distinctive odorant makes it easier for individuals to detect leaking gas using their sense of smell, enhancing public safety.

1.3.5 Safety Management

Safety management is one of the protocols that pipeline operators must follow to ensure that their pipelines operate safely and reliably. These guidelines outline how operators should identify, assess, prioritize, address, and validate the integrity of the pipeline system. While integrity management is mandatory for operators of transmission and distribution pipelines, Gathering lines are often exempt from these regulations. Gas transmission pipes in areas that are classified as High Consequence Areas (HCAs) -which are often more densely populated areas- should be examined within no more than seven years, according to safety management requirements. The inspection process is primarily carried out using internal inspection technologies, although pressure testing or direct assessment may also be employed, particularly when corrosion is suspected. Direct assessment, however, is only permissible under specific regulatory conditions. After each inspection, operators are required to take corrective actions for any issues detected, within defined timeframes [5].

1.4 Populated Areas

1.4.1 Public Facilities

When determining setback distances, not all facilities used by the public are classified as public facilities. A facility must be one that is regularly used by a significant number of people. Additionally, the evacuation options for that particular facility are considered in this classification. For example, a large, year-round campground with numerous campsites may be categorized as a public facility under the "Alberta Energy Resources" (AER) definition, whereas a smaller, rarely used campground may not meet this classification.

1.4.2 Unrestricted Country Development

Unrestricted country development refers to areas with permanent residential dwellings located outside urban centers, where the number of dwellings exceeds eight per quarter section, as depicted in Figure 5 [5].

1.4.3 Types of Development

- **Individual Residences and Farms:** Refers to independent buildings outside metropolitan areas with no more than twelve stable housing for every hundred hectares.
- **Growth of Unrestricted Country:** Areas with more than twelve stable housing for every hundred hectares located outside urban centers.
- **Public Facility:** Includes places such as recreational areas (e.g., campgrounds) or public buildings (e.g., rural schools or hospitals), and may also encompass institutions like libraries or museums.
- **Private Facility:** Areas where groups of people congregate, such as places of worship, daycare centers, rehabilitation facilities, or similar institutions.
- **Urban Center:** A city, town, village, or any other formally recognized urban area.

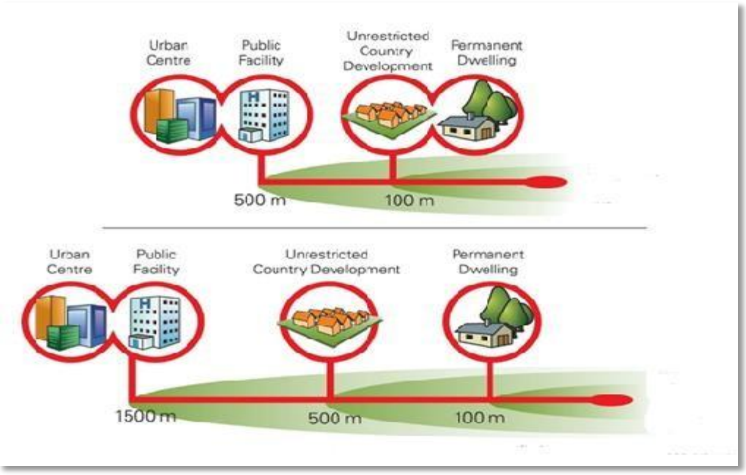


Figure 5: Shows distribution facilities for AER [5].

1.4.4 Differences Between a Farm Home and a Large Campground in Terms of Setback Distances

Setback distances are generally larger for urban environments and large recreational areas, such as campgrounds, compared to residential properties like farm homes. The reasoning behind this is to accommodate the need for safe evacuation in emergencies. It is simpler and faster to evacuate a single family from a farm than to evacuate a large group of individuals from a major campground or community. Therefore, these larger areas require extended setback distances to facilitate effective evacuation in the event of an emergency.

1.4.5 Distinction Between Setback Distances and Emergency Planning Zones (EPZ)

A setback **distance** refers to the minimum required physical distance between an energy facility—such as a gas pipeline or processing plant—and surrounding areas, including residential buildings, public spaces, or natural landscapes. The purpose of the setback is to reduce the risk of harm from potential hazards.

On the other hand, an **Emergency Planning Zone** (EPZ) designates an area surrounding a facility where the effects of a severe incident (such as a fire or explosion) might extend, potentially impacting people and the environment. While setbacks are primarily concerned with physical spacing to prevent immediate hazards, EPZs are concerned with broader emergency preparedness, taking into account the scope of the worst-case scenarios and the planning required to manage those risks.

1.4.6 Importance of Setback Distances

Setback distances are crucial to ensuring that energy facilities are not situated too close to populated areas and vice versa. These distances serve as protective buffers, lowering the risk of serious injury in the case of a facility breakdown or emergency. To illustrate this principle, imagine a speed limit of 30 kilometers per hour near a school playground. While this speed limit does not guarantee complete safety, it reduces the risk by allowing drivers to stop quickly in an emergency, such as when a child runs into the street. Similarly, setbacks are not a guarantee of absolute safety but are vital in lowering the potential risks associated with the operation of energy facilities. These distances serve as the "speed limits" of the energy sector, ensuring that there is enough time and space for appropriate emergency response and safety measures [5].

2 Equation Development and Explanation

2.1 Safety Setback "Rs"

A safety setback refers to the required minimum distance between an energy infrastructure, such as a pipeline, gas plant, or well, and nearby developments, including residential homes, rural communities, urban centers, or public facilities. The actual setback distance is determined by many circumstances, including the kind of development and whether the pipeline or facility handles hazardous materials such as sour gases.

In the event of a pipeline rupture, particularly in high-pressure natural gas pipelines, the consequences can be severe. For instance, when a rupture occurs, and the hole is small (e.g., less than twice the pipe's wall thickness), natural gas may leak out, creating a loud hissing sound. The gas can form a cloud that, when mixed with air in specific proportions (typically between 5-15% natural gas), can ignite upon contact with an ignition source, such as a spark. The result is an explosion followed by a localized fire. However, if the rupture is larger (more than four times the thickness of the pipe wall), the rupture may trigger a much more destructive event. The pressure from the escaping gas can create a large crater, and the resulting fire and explosion will cause more extensive damage, probably similar to the effects of a little nuclear detonation [6,7].

The resulting fire will generate significant heat, depending on various factors such as the distance from the rupture to potential ignition sources, the size of the explosion can vary significantly. While a precise safety distance to avoid all effects of the explosion cannot be easily determined, the thermal radiation from the fire can be calculated and used to establish a reasonable safety setback distance [9].

2.2 The Equation to Calculate Safe Setback Destination/ Rs

This section presents the equation of calculation of the minimum setback distance/ RS necessary to protect individuals from thermal radiation resulting from a fire caused by a high-pressure pipeline rupture. This calculation assumes that the fire involves the combustion of clean natural gas under lean conditions, meaning that sufficient air is available to prevent the formation of soot, which can increase the intensity of the thermal radiation. If the gas burns with other materials or in an over-rich combustion state, the amount of thermal radiation may be significantly higher, which would require a larger safety radius. The formula accounts for thermal radiation only and does not factor in other potential hazards, such as blast damage or the release of toxic substances like hydrogen sulfide (H_2S), which could pose dangers beyond the calculated safety radius. In addition, if the fire produces soot, the thermal radiation could increase up to four times, thereby expanding the necessary safety radius [9].

2.3 Formula Development for Gas Flow Rate and Thermal Radiation Impact

To calculate the radiant heat from a fire following a pipeline ruptures, it is necessary to first determine the gas flow rate from the rupture. Since natural gas flows from both ends of the rupture, the flow rate from one side is calculated and then doubled to account for the total flow. This mass flow rate is a key to understanding the scale of the fire and its potential thermal impact.

So, let P_a = the pressure in the pipeline distant from the rupture

And P_b = the pressure at the point of rupture after the rupture.

$\boldsymbol{Pb}$ usually represents the atmospheric pressure.

And $\boldsymbol{Dp}$: inside pipe diameter

, $\boldsymbol{En}$: The nozzle efficiency of converting natural gas pressure energy to kinetic energy in a long straight pipe.

In general:

$$\mathbf{0.90} < \boldsymbol{En} < \mathbf{0.99}$$

Uniform pipe cross-sectional area ($\boldsymbol{Ac}$) can be calculated as follows: $\boldsymbol{Ac} = \boldsymbol{\pi}\,(\frac{\boldsymbol{D_P}}{\mathbf{2}})^{\mathbf{2}}$

$\boldsymbol{X}$: Volume element's linear location along with the pipeline $\boldsymbol{Ac}\ \boldsymbol{d}$x.

$\boldsymbol{Rm}$ represents the gas's mass density as an indicator of the linear location ($\boldsymbol{X}$).

, $\boldsymbol{Rma}$: the gas's mass density at pressure (P_a).

, $\boldsymbol{Rmb}$: the gas's mass density at pressure (P_b).

The mass dM of the gas that occupies the volume element Ac dX is: dM = Rm. Ac dX

Let T represents time.

The gas linear velocity ***V*** is given by:

v = (dX/ dT)

The gas's linear kinetic energy in the volume element **Ac dX** is:

$$(\boldsymbol{dM} \,/\, \mathbf{2})\ (\boldsymbol{dX} \,/\, \boldsymbol{dT})\text{^}\mathbf{2}\ =\ (\boldsymbol{Rm}\ \boldsymbol{Ac}\ \boldsymbol{dX} \,/\, \mathbf{2})\ (\boldsymbol{dX} \,/\, \boldsymbol{dT})\text{^}\mathbf{2}$$

So, the kinetic energy density will be as: $\left(\frac{\mathbf{R_m}}{\mathbf{2}}\right) * (\frac{\mathbf{dX}}{\mathbf{DT}})^{\mathbf{2}}$

; **P**: pressure at **X**

So, the gas pressure potential energy that is already stored in the volume Ac dx is as follows:

P Ac dx

Pressure (P) represents the potential energy density of the gas at point (X).

Inside the pipe close to the point of rupture, the gas pressure potential energy density drops while the gas linear motion kinetic energy increases, increasing the linear velocity of the gas $\boldsymbol{v}$.

En: Is the nozzle efficiency at which gas pressure potential energy is transformed into gas kinetic energy for linear motion.

En is difficult to calculate; however, it often falls within the limits: **0.99 > En > 0.90**

It is worth noting that only a small proportion (1- En) of the pressure potential energy is transformed into heat. Energy conservation along the pipe requires the following:

$$-\,\boldsymbol{dP}\ \boldsymbol{En}\ =\ \boldsymbol{d}[(\boldsymbol{Rm} \,/\, \mathbf{2})\ (\boldsymbol{dX} \,/\, \boldsymbol{dT})^{\mathbf{2}}]$$

Or

$$-\ \mathbf{2}\ \boldsymbol{En}\ (\boldsymbol{Pb} - \boldsymbol{Pa})\ =\ [\boldsymbol{Rm}\ (\boldsymbol{dX} \,/\, \boldsymbol{dT})^{\mathbf{2}}]\boldsymbol{b} - [\boldsymbol{Rm}\ (\boldsymbol{dX} \,/\, \boldsymbol{dT})^{\mathbf{2}}]\boldsymbol{a}$$

Take subscript (**a**) denotes a parameter value at a location in the pipe distant from the rupture.
And subscript (**b**) represents a variable amount at the rupture site. Thus, the linear gas velocity at the moment of rupture is (υ_b).
So, the total volume of flow for a single pipe at the point of rupture is that; **Rmb Ac** υ_b

The limited integration from (Pa to Pb) yields:

$$-2\,En\,(Pb - Pa) = [Rm\,(dX / dT)^2]b - [Rm\,(dX / dT)^2]a$$

Suppose the natural gas pipeline's supervisory control system closes valves that isolate upstream and downstream of the pipe breach. So, the situation at the site of each of these valves is no flow, or represented scientifically in terms of the gas stream:

$$\left(\frac{dx}{dT}\right)_a = \textbf{Zero}$$

Consequently,

$$2\,En\,(Pa - Pb) = [Rm\,(dX / dT)^2]b$$

Or

$$[dX / dT]_b = \sqrt{[2\,En\,(Pa - Pb) / Rmb]}$$

F_m represents the outgoing gas mass and flow rate from a single pipe.

So, F_m

$$= Rmb\,Ac\,[dX / dT]_b$$

$$= \sqrt{Rmb\,Ac\,[2\,En\,(Pa - Pb) / Rmb]}$$

$$= \sqrt{Ac\,[2\,En\,(Pa - Pb)\,Rmb]}$$

Take E_C represents the amount of heat released during combustion per unit (m) of natural gas. Thus, the total burning release of (H) per unit (T) can be calculated as: $\mathbf{H = 2\,F_m \times E_C}$
Whereas **# 2** indicates that the rupture is fed by **2** pipes.

Let ***Fr*** be the fraction of the combustion heat that is emitted via radiation.
Let ***Rz*** = radius from the center of the flame to a surface subject to radiation damage.

Assume that the radiation is evenly distributed over a sphere with radius Rz_1 and surface area $4\pi Rz^2$. Then at radius Rz_1 the radiation intensity/ unit area is: $Rz_1 = (H\,Fr)/ (4\pi Rz^2)$.

Suppose that, to minimize skin damage, the radiation intensity should be less than the maximum intense solar radiation incident on the surface of the planet **(1365** $\frac{W}{m^2}$**);** This parameter is referred to as the Solar Irradiance.
Therefore, in terms of radiant energy, a secure distance Rs from the center of the flame is expressed as:

$$(H\,Fr) / (4\,\pi\,Rs^2) = 1365\,watts / m^2$$

Or

$$Rs = \sqrt{[(H\,Fr) / (4\,\pi \times 1365\,watts / m^2)]}$$

$$= \sqrt{[(2\,Fm\,Ec\,Fr) / (4\,\pi \times 1365\,watts / m^2)]}$$

Since natural gas mass flow (F_m) is calculated using the following formula:

$$Fm = Ac\sqrt{[2\,En\,(Pa - Pb)\,Rmb]}$$

$$= \pi(Dp / 2)^2 \sqrt{[2\,En\,(Pa - Pb)\,Rmb]}$$

Now by bringing together the formulas for R_s & F_m , we get:

$$Rs = \sqrt{[(2\,Fm\,Ec\,Fr) / (4\,\pi X\,1365\,watts / m^2)]}$$

$$= \sqrt{[(2\,\pi(Dp / 2)^2 \sqrt{[2\,En\,(Pa - Pb)\,Rmb]}\,Ec\,Fr) / (4\,\pi \times 1365\,watts / m^2)]}$$

$$= Dp\,[En\,(Pa - Pb)]^{0.25} \sqrt{[(\sqrt{[2\,Rmb]}Ec\,Fr) / (8 \times 1365\,watts / m^2)]}$$

The value of ($\mathbf{F_r}$) can be found at **[5]**, which discovered that the radiation emission from a 207 Mw natural gas flame measured at ground level, 11.9 m ≈(12 m) from flame center, was 3.37 $\frac{kw}{m^2}$:

$$4\,\pi(11.9\ m)^2 = 1778.62\ m^2$$

Hence the emitted radiation was:

$$6.37\ kW\ /\ m^2 \times 1778.62\ m^2 = 11330\ kW$$
$$= 11.330\ MW$$

Hence:

$$Fr = 11.330 \qquad MW\ /\ 207\ MW$$
$$Fr = 0.0547$$

($\mathbf{F_r}$) value is consistent with other Fr statistics for lean burn flame retention natural gas burners published by **CERI** [2].

2.4 Mathematically; It can be simplified to:

$$\mathbf{R_{mb}} = \frac{16\ gm}{22.4\ lit} = \frac{16 \times 10^{-3}\ \text{kg}}{22.4 \times 10^{-3}\ m^3} = \mathbf{0.714}\ \frac{\text{kg}}{\text{m}^3}$$; which is equals to density of natural gas at standard Pressure & Temperature.

$$\textbf{Then;}\quad \mathbf{Ec = 10.4}\ \frac{\text{kWh}}{\text{m}^3} * \frac{1\ \text{m}^3}{0.714\ \text{kg}} * \mathbf{3600}\ \frac{\mathbf{s}}{\mathbf{h}}$$

$$\mathbf{Ec = 52437}\ \frac{\text{kj}}{\text{kg}}$$

So,

$$Rs = Dp\,[En\,(Pa - Pb)]^{0.25} \sqrt{\left[\frac{(\sqrt{[2\ Rmb]}\ Ec\ Fr)}{(8 \times 1365\ watts\ /\ m^2)}\right]}$$

$$= Dp[En(Pa - Pb)]^{0.25} \sqrt{\left[\frac{(\sqrt{\left[2 \times .714 \frac{kg}{m^3}\right]} \times 52437 \frac{kJ}{kg} \times .0547)}{(8 \times 1365 \frac{watts}{m^2})}\right]}$$

$$= Dp[En(Pa - Pb)]^{0.25} \sqrt{\left[\sqrt{[1.428\ \frac{kg}{m^3}]} \times .26266\ kJ\ \frac{m^2}{kg} - watts \times 10^3 \frac{J}{kJ}\right]}$$

$$= Dp\,[En\,(Pa - Pb)]^{0.25} \sqrt{[1.195\ kg^{0.5} \times 1\ m^{-1.5} \times 262.66\ J\ m^2/kg - watts]}$$

$$= Dp\,[En\,(Pa - Pb)]^{0.25} \times 17.71\ kg^{0.25} \times 1m^{-0.75} \times 1\ m\ (J\ /\ kg - watts)^{0.5}$$

$$= 17.71\ Dp\,[En\,(Pa - Pb)]^{0.25} \times 1kg^{0.25} \times 1m^{-0.75} \times 1\ m\ (watt\ s\ /\ kg - watts)^{0.5}$$

$$= \mathbf{17.71\ 17.71\ Dp} * (\mathbf{En} * [\mathbf{Pa - Pb}])^{\wedge}\tfrac{1}{4} \quad \times \mathbf{1\ kg^{-0.25} \times 1\ m^{0.25} \times 1\ S^{0.5}}$$

$$\boldsymbol{Rs} = \mathbf{17.71\ Dp\ (En\ [Pa - Pb]/\ pascal)^{0.25}}$$

$$\boldsymbol{Rs} = \mathbf{17.71\ Dp} * (\mathbf{En} * [\mathbf{Pa - Pb}])^{\wedge}\tfrac{1}{4} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If the pipe diameter (Dp, m) and the operating pressure (Pa - Pb) is in Pa, so, the equation calculates the secure setback distance (Rs, m).

Verify the units:

$$[\boldsymbol{Pa.}]^{\frac{1}{4}} = \left[\frac{newton's}{m^2}\right]^{\frac{1}{4}} = \left[\frac{Kg.m}{m^2\ S^2}\right]^{\frac{1}{5}} = \frac{\text{Kg}^{\frac{1}{4}}}{(\text{m})^{\frac{1}{4}} \cdot (S)^{\frac{1}{5}}}$$

For calculations that are practical, it can assume that: $(\boldsymbol{En})^{\wedge\frac{1}{4}} = \mathbf{1}$
This assumption might bring about as much a **2.7 %** error in the calculated **Rs** amount. However this assumption reduces the calculation for **Rs** effectively to make it appropriate for practical regulation usage [2].

2.5 . Analysis of results:

- **@** Rz = Rs

Radiation intensity from the gas's inferno equal solar radiation, Therefore, human skin damage is therefore limited to sunburn-like effects.

- @ $Rz_1 = [\frac{Rs}{2}]$ …………………………………………… 2

Natural gas inferno emits four times as much radiation as the sun. This is the highest level of radiation that normally prepared firemen can withstand. Therefore, in the region described as:

$$[\frac{Rs}{2}] > Rz_1$$

Second fires normally burn unabated unless subdued using water bombers or other similar special machinery.

- @ $\boldsymbol{Rz_2} = [\frac{Rs}{4}]$ ……………………………………………………. 3

Natural gas inferno emits sixteen times as much radiation as the sun. In the area: $[\frac{Rs}{4}] > Rz_2$
Regardless of the existing firefighting capability, practically all flammable surfaces ignite quickly and completely, resulting in catastrophic property loss.

2.6. Second the ignition:

Immediately after the natural the natural gas fire began almost quickly, exposing combustible surfaces in the zone: $[\frac{Rs}{4}] > Rz$
But from an asset damage standpoint, the larger difficulty is that fires that are directly ignited within this zone:

$$[\frac{Rs}{4}] > Rz$$

Quickly spread into the region: $[\frac{Rs}{4}] < Rz < [\frac{Rs}{2}]$

Because the thermal radiation levels in the region: $Rz < [\frac{Rs}{2}]$

Are too high for firefighters to function in that region.

History has demonstrated that the practical way of minimizing property damage in the region:

$$[\frac{Rs}{2}] > Rz > [\frac{Rs}{4}]$$

Is to employ water bombers to reduce the growth of fires by second combustion. Assuming a regular firefighter response without water bombers, the area that will most likely be damaged by subsequent flames is the ring defined by: $[\frac{Rs}{4}] < Rz < [\frac{Rs}{2}]$
Area within this circuit is almost three times the area described as follow: $[\frac{Rs}{4}] > Rz$
That burns with direct ignition [2, 6].

2.7 Reduction of Damage

Theoretical studies and the field observations have consistently shown that deep snow cover plays a critical role in mitigating the damage associated with a burning natural gas pipeline. Snow's reflective properties help divert infrared radiation upwards, thereby reducing the amount of heat transferred to the ground. Additionally, as the snow melts, it produces water that further absorbs heat, effectively cooling nearby surfaces and preventing them from reaching temperatures sufficient to ignite. This combination of heat reflection and thermal absorption through the meltwater serves as an important mechanism for controlling the spread of the fire and minimizing secondary ignition risks.

Ex., Sirte company pipeline [1]:

$Dp = 0.856\ m$

$Pb = 14.7\ psia = 1\ bar = 101\ kPa = 1.01\ X\ 10^5 N/m^2$

$Pa = 480psia = 32.65bar = 3297.96kPa = 32.9796X10^5 N/m^2$

Hence:

$$Rs = 17.71\ Dp\ [En\ (Pa - Pb) / \text{Pascal}]^{0.25}$$

So, $Rs = 17.71 \times 0.856\ [1 \times 31.9696 \times 10^5]^{0.25} = 641\ m$

$Rz_1 = (Rs/2) = 320.5\ m$, $Rz_2 = (Rs/4) = 160.25\ m$

Note:

Eq. (1) gives the safety setback Rs for continuous flow or if the valves fail, which will be calculated late if the valves are working correctly and Pa drop when the valves are closed.

$$Rs = 17.71\ Dp\ [En\ (Pa - Pb)]^{0.25} \text{-------------------------------}(4)$$

3. Data Analysis, Results and Discussion

Analyze the data from Table 1, Table 2 and Table 3 ***Rs***, ***Rz₁*** and ***Rz₂*** for different types of pipelines and different operating pressure using *Eq.* (1), *Eq.* (2) and *Eq.* (3).

Safety setback (***Rs***) decreasing by decreasing diameter of pipeline that can been show at Figure 6 , Figure 7 also Rz_1 at Figure 8, Figure 9 and Rz_2 at Figure 10, Figure 11.

Table 1: Pipeline diameters and safety setback ***Rs*** for different operation Pressure [6].

Pipline Diameter , inshes	Pipline Diameter , meters	Rs Setback , meters @ oressure 50 psi	Rs Setback , meters @ oressure 100 psi	Rs Setback , meters @ oressure 200 psi	Rs Setback , meters @ oressure 350 psi	Rs Setback , meters @ oressure 500 psi	Rs Setback , meters @ oressure 600 psi	Rs Setback , meters @ oressure 650 psi	Rs Setback , meters @ oressure 700 psi	Rs Setback , meters @ oressure 1000 psi	Rs Setback , meters @ oressure 1400 psi
4	0.1016	40	50	60	70	77	81	82	84	92	100
6	0.1524	60	75	91	105	115	121	123	126	138	150
8	0.2032	80	100	121	140	154	161	165	168	184	200
10	0.254	100	125	151	175	192	202	206	210	230	250
12	0.3048	120	149	181	210	231	242	247	252	276	300
14	0.3556	140	174	212	246	269	282	288	294	322	350
16	0.4064	160	199	242	281	308	323	329	336	367	400
18	0.4572	180	224	272	316	346	363	370	378	413	450
20	0.508	200	249	302	351	385	403	412	419	459	500
30	0.762	300	374	454	526	577	605	617	629	689	750
48	1.2192	480	598	726	842	923	968	988	1007	1102	1200

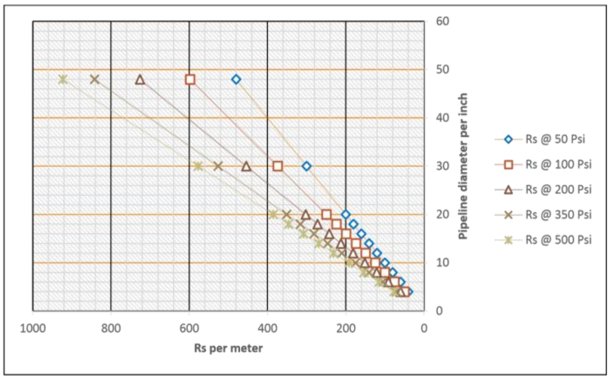


Figure 6: decreasing ***Rs*** by decreasing pipeline diameter ***Dp*** for operating pressures from **50** Psi to **500** Psi.

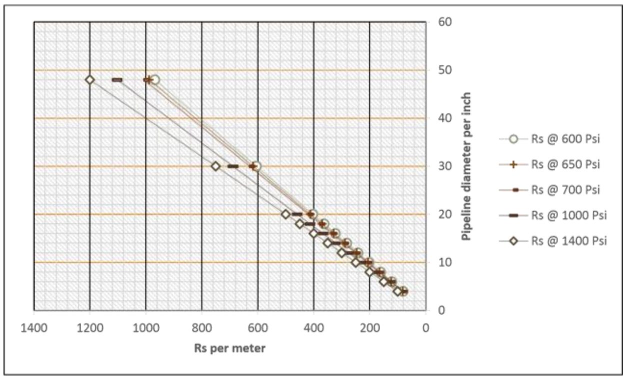


Figure 7: decreasing ***Rs*** by decreasing pipeline diameter ***Dp*** for operating pressures from **600** Psi to **1400** Psi.

Table 2 : Pipeline diameters and safety setback Rz_1 for different operation Pressure.

Pipline Diameter, inshes	Pipline Diameter, meters	Setback Rz_1, meters @ pressure 50 psi	Setback Rz_1, meters @ pressure 100 psi	Setback Rz_1, meters @ pressure 200 psi	Setback Rz_1,, meters @ pressure 350 psi	Setback Rz_1,, meters @ pressure 500 psi	Setback Rz_1, meters @ pressure 600 psi	Setback Rz_1, meters @ pressure 650 psi	Setback Rz_1, meters @ pressure 700 psi	Setback, Rz_1, meters @ pressure 1000 psi	Setback, Rz_1, meters @ pressure 1400 psi
4	0.1016	20	25	30	35	38.5	40.5	41	42	46	50
6	0.1524	30	37.5	45.5	52.5	57.5	60.5	61.5	63	69	75
8	0.2032	40	50	60.5	70	77	80.5	82.5	84	92	100
10	0.254	50	62.5	75.5	87.5	96	101	103	105	115	125
12	0.3048	60	74.5	90.5	105	115.5	121	123.5	126	138	150
14	0.3556	70	87	106	123	134.5	141	144	147	161	175
16	0.4064	80	99.5	121	140.5	154	161.5	164.5	168	183.5	200
18	0.4572	90	112	136	158	173	181.5	185	189	206.5	225
20	0.508	100	124.5	151	175.5	192.5	201.5	206	209.5	229.5	250
30	0.762	150	187	227	263	288.5	302	308.5	314.5	344.5	775
48	1.2192	240	299	363	421	461.5	484	494	503.5	551	600

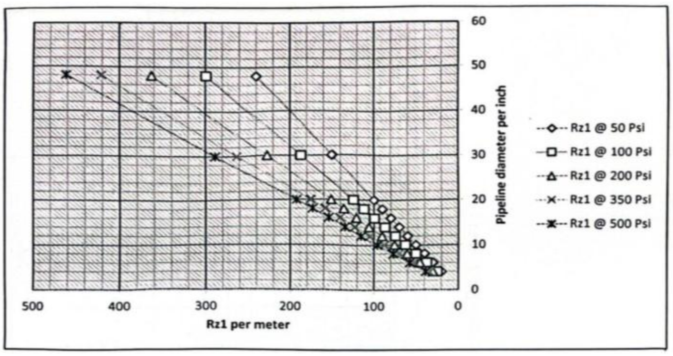


Figure 8: decreasing Rz_1 by decreasing pipeline diameter Dp for operating pressures from **50** Psi to **500** Psi.

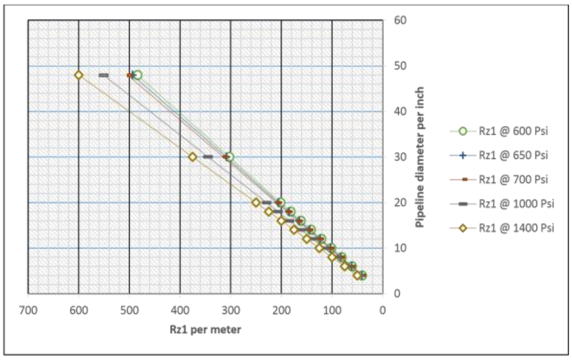


Figure 9: decreasing Rz_1 by decreasing pipeline diameter Dp for operating pressures from **600** Psi to **1400** Psi.

Table 3: Pipeline diameters and safety setback Rz_2 for different operation Pressure.

Pipline Diameter, inshes	Pipline Diameter, meters	Setback Rz_2, meters @ pressure 50 psi	Setback Rz_2, meters @ pressure 100 psi	Setback Rz_2, meters @ pressure 200 psi	Setback Rz_2,, meters @ pressure 350 psi	Setback Rz_2,, meters @ pressure 500 psi	Setback Rz_2, meters @ pressure 600 psi	Setback Rz_2, meters @ pressure 650 psi	Setback Rz_2, meters @ pressure 700 psi	Setback, Rz_2, meters @ pressure 1000 psi	Setback, Rz_2, meters @ pressure 1400 psi
4	0.1016	10	12.5	15	17.5	19.25	20.25	20.5	21	23	25
6	0.1524	15	18.75	22.75	26.25	28.75	30.25	30.75	31.5	34.5	37.5
8	0.2032	20	25	30.25	35	38.5	40.25	41.25	42	46	50
10	0.254	25	31.25	37.75	43.75	48	50.5	51.5	52.5	57.5	62.5
12	0.3048	30	37.25	45.25	52.5	57.75	60.5	61.75	63	69	75
14	0.3556	35	43.5	53	61.5	67.25	70.5	72	73.5	80.5	87.5
16	0.4064	40	49.75	60.5	70.25	77	80.75	82.25	84	91.75	100
18	0.4572	45	56	68	79	86.25	90.75	92.5	94.5	103.25	112.5
20	0.508	50	62.25	75.5	87.75	96.25	100.75	103	104.75	114.75	125
30	0.762	75	93.5	113.5	131.5	144.25	151.25	154.25	157.25	172.25	187.5
48	1.2192	120	149.5	181.5	210.5	230.75	242	247	251.75	175.5	300

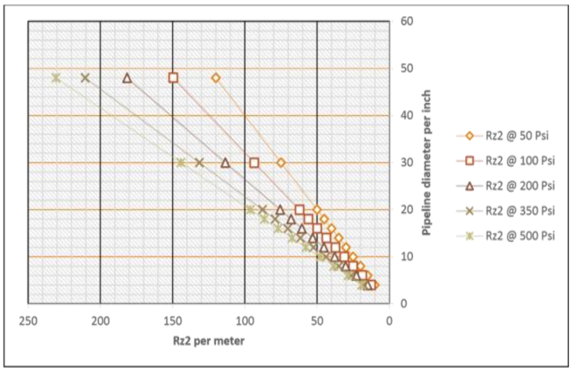


Figure 10: decreasing $\boldsymbol{Rz_2}$ by decreasing pipeline diameter $\boldsymbol{Dp}$ for operating pressures from **50** Psi to **500** Psi.

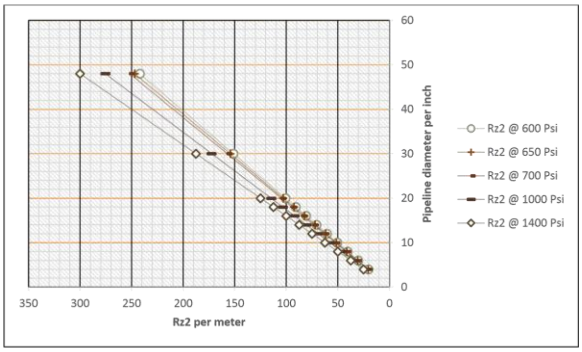


Figure 11: decreasing $\boldsymbol{Rz_2}$ by decreasing pipeline diameter $\boldsymbol{Dp}$ for operating pressures from **600**Psi to **1400** Psi.

3.1 $\boldsymbol{Rs}$ & Pressure Drop:

If a rupture happened to pipeline and valves is closed the pressure will release through the rupture and cause a pressure drop and result that the safety setback **Rs** (from Eq. (4)) distance decreasing show at figure 12, also $\boldsymbol{Rz_1}$ at figure 13, and $\boldsymbol{Rz_2}$ at figure 14.

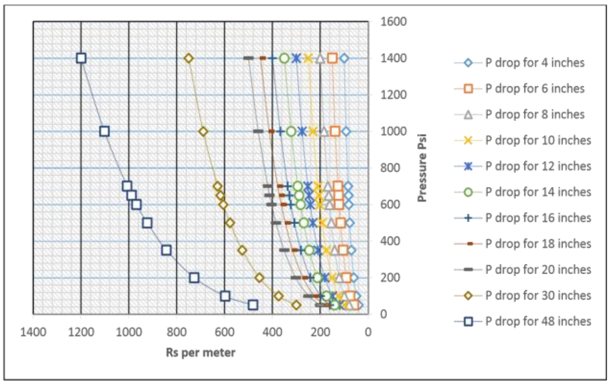


Figure 12: Shows decreasing $\boldsymbol{Rs}$ by pressure drop $\boldsymbol{Pa}$ for pipeline diameter from **4** Inches to **48** Inches.

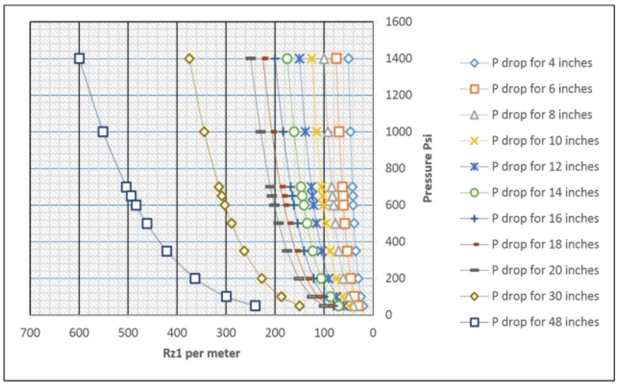


Figure 13: decreasing $\boldsymbol{Rz_1}$ by pressure drop $\boldsymbol{Pa}$ for pipeline diameters (4,6,8,10,12,14,16,18,20,30,48) Inches.

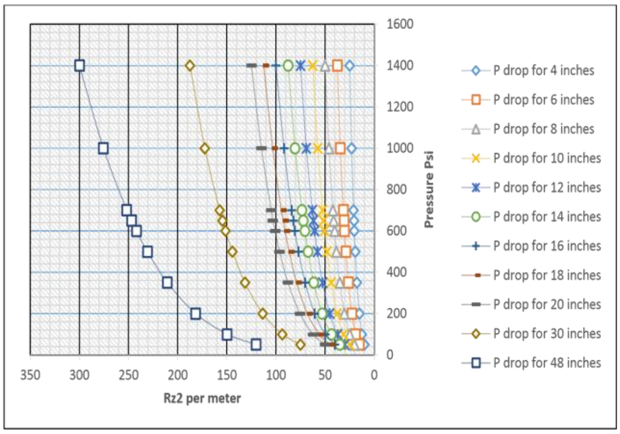


Figure 14: decreasing $\boldsymbol{Rz_2}$ by pressure drop $\boldsymbol{Pa}$ for pipeline diameters (4,6,8,10,12,14,16,18,20,30,48) Inches.

3.2. Sirte Company Data Analysis:

Pipeline diameter 0.856 meters and operating pressure **480 Psi** with length 18 km with maximum operating pressure design **823 Psi** and one valve. By applying the Eq. (1), Eq. (2), Eq. (3). And different operating pressure as at table 4, And decreasing $\boldsymbol{Rs}$ and pressure drop figure 15, decreasing $\boldsymbol{Rz_1}$ and pressure drop figure 16, And decreasing $\boldsymbol{Rz_2}$ and pressure drop figure 17.

For 480 Psi, $\boldsymbol{Rs}$ = 641.0274 meters, $\boldsymbol{Rz_1}$ = 320.5137 meters, $\boldsymbol{Rz_2}$ = 160.2569 meters
For 823 Psi, $\boldsymbol{Rs}$ = 735.93 meters, $\boldsymbol{Rz_1}$= 367.965 meters, $\boldsymbol{Rz_2}$= 183.9825 meters

Table 4: For Sirte company pipeline and different operating pressure [1].

Dp , m	Pb, N/m^2	Pa, psi	Pa, N/m^2	Rs, m	Rz_1 , m	Rz_2, m
0.856	10100	**14.7**	**10100**	**0**	**0**	**0**
0.856	10100	14.75	101343.5	65.26583	32.63291	16.31646
0.856	10100	15	103061.2	102.1465	51.07327	25.53663
0.856	10100	20	137415	209.4172	104.7086	52.35429
0.856	10100	40	274829.9	309.5448	154.7724	77.38619
0.856	10100	60	412244.9	358.07	179.035	89.51749
0.856	10100	80	549659.9	392.3482	196.1741	98.08704
0.856	10100	100	687074.8	419.4504	209.7252	104.8626
0.856	10100	120	824489.8	442.1305	221.0652	110.5326
0.856	10100	140	961094.8	461.8933	230.8879	115.4439
0.856	10100	180	1236735	494.8933	247.4466	123.7233
0.856	10100	200	1374150	509.2279	254.614	127.307
0.856	10100	220	1511565	522.445	261.2225	130.3112
0.856	10100	240	1648980	534.7289	267.3644	133.6822
0.856	10100	260	1786395	546.2202	273.1101	136.555
0.856	10100	280	1923810	557.0288	278.5144	139.2572
0.856	10100	300	2061224	567.2425	283.6213	141.8106
0.856	10100	320	2198639	576.9325	288.4663	144.2331
0.856	10100	340	2336054	586.1575	293.0788	146.5394
0.856	10100	360	2473469	594.9665	297.4832	148.7416
0.856	10100	380	2610884	603.4006	301.7003	150.8502
0.856	10100	400	2748299	611.4953	305.7476	152.8738
0.856	10100	420	2885714	619.2806	309.6403	154.8202
0.856	10100	440	3023129	626.783	313.3915	156.6957
0.856	10100	460	3160544	634.0252	317.0126	158.5063
0.856	10100	480	3297959	641.0274	320.5137	160.2569
0.856	10100	500	3435374	647.8074	323.9037	161.9552
0.856	10100	520	3572789	654.381	327.1905	163.5952
0.856	10100	540	3710204	660.7622	330.3811	165.1905
0.856	10100	560	3847619	666.9637	333.4819	166.7409
0.856	10100	580	3985034	672.9969	336.4985	168.2492
0.856	10100	600	4122449	678.8721	339.4361	169.718
0.856	10100	620	4259864	684.5986	342.2993	171.1496
0.856	10100	640	4397279	690.1849	345.0924	172.5462
0.856	10100	660	4534694	695.6387	347.8194	173.9097
0.856	10100	680	4672109	700.9672	350.4836	175.2418
0.856	10100	700	4809524	706.1769	353.0885	176.5442
0.856	10100	720	4946939	711.2738	355.3669	177.8184
0.856	10100	740	5084354	716.2634	358.1317	179.0658
0.856	10100	760	5221769	721.1508	360.5754	180.2877
0.856	10100	780	5359184	725.9409	362.9704	181.4852
0.856	10100	800	5496599	730.638	365.319	182.6595
0.856	10100	823	5654626	735.93	367.965	183.9825

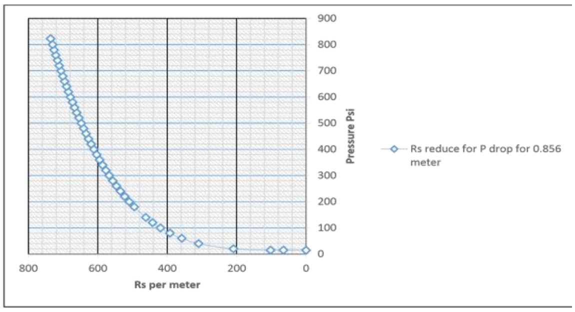


Figure 15: Decreasing Rs by pressure drop Pa for pipeline diameter 0.856 meters.

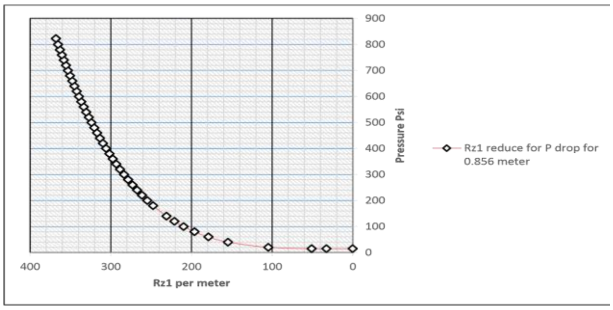


Figure 16: Shows decreasing Rz_1 by pressure drop Pa for pipeline diameter 0.856 meters.

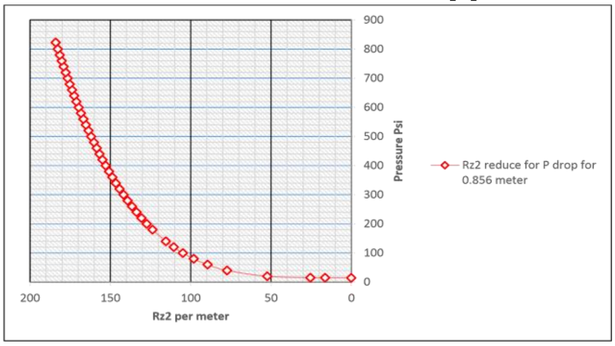


Figure 17: Shows decreasing Rz_2 by pressure drop Pa for pipeline diameter 0.856 meter.

4. Conclusions:

If a high-pressure natural gas pipeline ruptures, it will erupt, leading to a steady-state fire flame. This flame generates a high degree of heat radiation, making it difficult to approach with traditional firefighting equipment. Radial areas were used for estimating.

Rs < R, is safety radius for peoples.

Rs > Rz > Rz_1, is for firefighters supported with water pumps.

Rz_1 > Rz, Buildings, crops, and other flammable substances within this radius of the pipeline rupture/ fire will spontaneously ignite and be completely destroyed.

A minimum safety setback from gas networks is determined by pipe diameter along with operational pressure, in a positive relationship.

5. Recommendations:

The researcher recommends that a minimum setback distance of 370 meters be maintained from the centerline of the Sirte Company pipeline to all human-occupied structures and areas where individuals routinely gather outdoors. The setback should be rigorously enforced by municipalities throughout the pipeline's operating life. It is critical to recognize that the radiation released from a pipeline rupture or fire is sufficiently powerful to feasible response from fire departments is to allow the fire to burn itself out, while efforts are made to cool the surrounding areas. Moreover, expecting individuals within the Rz1 radius of a pipeline rupture or fire that can be rescued by emergency response personnel is unreal.

Given extreme hazards, Local government ought to focus on enforcing the 370-meter setback over the existing 100-meter requirement. The zone between 100 and 370 meters is particularly vulnerable to potential harm, including injury and property damage, which could result in legal disputes.

Furthermore, local authorities should prioritize public education campaigns to inform residents living near gas pipelines about the risks associated with activities such as excavation or other actions that could inadvertently cause harm. Increased awareness and education on safety practices are critical in reducing the risk of accidents and fatalities.

6. References:

[1] https://libyanlines.wordpress.com/tag/Libya.

[2] Alhadad, E. H. (2015) 5-8, 1-30, Engineering at Sirte Company.

[3] PIPA Report, No. 2. (November 2010) , The Pipelines and Informed Planning Alliance, *Partnering to Further Enhance Pipeline Safety*, https://pstrust.org/docs/PIPA-Report-Final-20101117.pdf

[4] https://www.phmsa.dot.gov/

[5] Alberta Energy Resource, AER 2014. Calgary: A.T., 2014, https://www.aer.ca

[6] M. T. Markiewicz, *Consideration of Risks to People and the Environment Related to Accidents on Natural Gas Transmission Pipelines in LUP and SEA Processes in Poland*, Warsaw University of Technology, 2023
[7] Canada Energy Regulator, *Pipeline Regulation in Canada - A Guide for Landowners and the Public*, Canada Energy Regulator, 2023, https://www.cer-rec.gc.ca.
[8] Gore, J.P., Faeth, G.M., Evans, D. and Pfenning, D.B. (1986), Structure and radiation properties of large-scale natural gas/air diffusion flames. Fire Mater., 10: 161-169. https://doi.org/10.1002/fam.810100311
[9] Sklavounos, S., & Rigas, F. (2006). Estimation of safety distances in the vicinity of fuel gas pipelines. Journal of Loss Prevention in the Process Industries, 19(1), 24-31. doi: https://doi.org/10.1016/j.jlp.2005.05.002