

ASSESSMENT OF OIL AND GAS PIPELINE RISKS

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ABSTRACT

Pipelines are commonly used to transport oil and gas because they are more energy-efficient than other methods of transporting oil and gas. The possible hazards from release of oil or gas from a pipeline leakage or rupture are explosion, fire or pollution of the environment. A computer programme written to compute unsteady flow in natural gas pipeline was used to calculate the rate of gas release from a ruptured 49km pipeline section. After one thousand seconds when about 70% of the gas had been released, the explosion hazard zone had grown to a radius of about 252m from the ruptured pipeline. Pipelines should be patrolled by ground and aerial surveillance teams and they should be inspected regularly to avoid catastrophic failure and ensure the safety of the pipeline system.

INTRODUCTION

Pipelines are commonly used to transport oil and gas. It has been found that pipelines are more energy-efficient than other methods of transporting oil and gas, and even other forms or sources of energy. For instance in the U.S.A., pipelines were about 50% more energy efficient than transportation by railway, four times more efficient than transportation by road and it was approximately three times more costly to transport electricity via cables than it was to transport an equivalent amount of energy through an oil or gas pipeline [1].

Nigeria is served by networks of oil and gas pipelines. A pipeline

over 600km carries crude oil from Niger Delta to Kaduna. There are about 15 depots linked to the refineries by a network of pipelines which carry petroleum products. As at 1991, Nigerian Gas Company had more than 1000km of pipeline with seven gas pipeline systems, fourteen compressor stations and a total capacity of over 2 billion standard cubic feet per day (SCFD) [2]. There are also hundreds of kilometers of underwater pipelines linking well-head production platforms, gas compression platforms to production platforms and offshore production facilities with terminal and loading facilities.

Apart from being energy-efficient, pipelines also have the advantage that they can be buried so that they do not mar the environment like large power transmission lines. It is also safer to transport petroleum products by pipeline than by road or railway in tankers since the risk of accident during transportation is reduced to the bare minimum.

2. LEAKAGE AND RUPTURE OF PIPELINES

More attention has been given to blowout from wells than spillage from pipelines [3]. However, because pipelines operate at high pressure (in the range 50 - 150 bar), a pipeline segment may contain several thousand tons of natural gas or oil. Thus, in the event of a pipeline rupture, the pollution and economic losses due to spillage may be as high as that due to blow out from a well.

Generally, the use of pipelines for transporting oil and gas meets the need of informed citizens of Nigeria who in their desire for sustainable development, want cheap, reliable, and plentiful supply of these products which are important sources of energy, with no harmful environmental effects. Apart from the occasions when there are shortages of these products, the only exception to meeting these requirements occur whenever there is pipeline leakage or rupture.

Pipeline leakage can be caused by corrosion which may occur especially where the pipeline passes through salty water or swamps. Loss of pipeline inventory due to leakage is normally small. It is pipeline rupture that causes greater environmental hazard. Pipeline rupture may be caused by various reasons.

People may cause pipeline rupture due to sabotage during periods

of political instability. For instance the government of Pakistan attributed a natural gas pipeline rupture in 1989 which caused fire outbreak and death of twelve people, to sabotage [4]. Anibueze [5] estimated the oil spill cases in the Western zone of operation of Nigerian Petroleum industry from 1980 to 1990 due to sabotage to be 49.8% while the cases caused by equipment failure were estimated to be 43.7%.

Fire outbreak or explosion in the vicinity of the pipeline, say on a platform, a compressor or pump station can also cause pipeline rupture.

Excessive pressure in the pipeline during transients caused by sudden valve closure may cause the pipeline to rupture. Natural disasters such as flood, earthquake and land slides say due to erosion can also cause pipeline rupture.

Damage to a pipeline during excavation can also cause the pipeline to rupture.

Along oil and gas pipeline there are valves, regulators, pig traps and compressors or pumps. The size of pumps or compressors, their operating conditions and spacing of their stations are based on extensive economic studies. The valves can be operated manually or automatically. The valves equipped with devices for automatic closure, may be shut automatically in the presence of steep pressure gradients along the line such as may be caused by pipeline rupture, resulting in emergency shutdown.

Apart from accidental pipeline rupture, there are other instances in which natural gas is discharged to the atmosphere during the operation of the pipeline. Under emergency conditions, the piping in a compressor station is emptied to the atmosphere at a safe distance by opening gas operated vent valves after the station shut off valves have been closed to isolate the station. During blowdown and line depressurization of a pipeline segment which is to be maintained, it is first isolated by closing the line break valves before and after the segment, then the gas is vented and dispersed to the atmosphere. The pigs launching and receiving traps also have vent systems for discharging to the atmosphere the gas in the pig trap before and after pigging operations.

However, these discharges are controlled and they are of limited

quantities. The ones that pose great threat to the environment is that due to accidental rupture of the pipeline.

3. EFFECTS OF OIL AND GAS SPILLS

In the event of a pipeline rupture, several thousand tons of oil or gas would leak out within the time required to stop the spill through pump (or compressor) and valve shutdown. This represents a great economic loss. Anibueze[5] estimated the average annual direct economic loss in Nigeria due to oil spills between 1980 and 1990 to be two hundred and seventy thousand dollars. In addition to the direct economic loss, there is possibility of great damage to the environment due to oil or gas spill.

An accidental massive release of oil or gas can give rise to substantial mechanical damage or nearby facilities. It may also lead to large fires and explosions.

In the case of subsea pipeline connected to platforms, a break in it could lead to formation of gas or oil plumes which could be carried towards the platform. The plume may cause instability of platform or ship caught in it due to partial loss of buoyancy[3].

Oil spills can destroy farm crops. Creeks, streams and fish ponds may be poisoned and thereby result in loss of fish and other aquatic lives. Pollution of drinking water due to oil spill may endanger human lives.

Large quantities of unburned hydrocarbons released to the atmosphere due to oil or gas spill can react in sunlight with nitrogen oxides released from industrial smoke stacks and automobile exhausts to form photochemical oxidants and other compounds. The compounds formed may adversely affect materials, vegetation, and human health. However, if the level of NO_x in the air is very low, the formation of these photochemical oxidants is alleviated [6].

4. HAZARD ANALYSIS OF NATURAL GAS PIPELINE RUPTURE

It is necessary to know the rate of loss of gas from a pipeline rupture to be able to calculate the dispersion range and ground concentration of the air-gas mixture.

The flow in a natural gas pipeline after rupture was modelled as unsteady one-dimensional isothermal compressible flow.

The conservation equations for mass and momentum are:

$$\frac{\partial \rho}{\partial t} + u \frac{\partial \rho}{\partial x} + \rho \frac{\partial u}{\partial x} = 0 \quad (1)$$

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + \frac{1}{\rho} \frac{\partial p}{\partial x} + F = 0 \quad (2)$$

$$\text{Where} \quad F = \frac{2f}{d} u |u| \quad (3)$$

ρ = Density, t = Time, Velocity, x = Axial distance

P = Pressure, F = Friction force per unit mass,

F = Friction Factor, and d = Pipe diameter.

The set of hyperbolic partial differential equations was solved by a numerical method of characteristics. The characteristics having reciprocal slopes $(u + 1)$ and $(U - 1)$ are labelled OV and TV in Figure 1 which shows the characteristics reaching internal and boundary grid points for flow in which the velocity is less than isothermal speed of sound. The non-dimensional velocity, $U = u/c$ where c = isothermal speed of sound. In Figure 1, the non-dimensional time and axial distance along the pipeline are $Z = tc/l_0$ and $X = x/l_0$ respectively, where l_0 = pipe length taken as reference length.

It can be shown that the finite difference approximation of the non-dimensional compatibility equations along the characteristics OV and TV, respectively, are

$$U_v - U_o + (\ln P'_v - \ln P'_o) = -F'_{ov} \Delta Z \quad (4)$$

$$U_v - U_T - (\ln P'_v - \ln P'_T) = -F'_{TV} \Delta Z \quad (5)$$

Where $P' = P/P_o$, $F' = Fl_0/c^2$, $\Delta Z = \Delta t \cdot c/l_0$ and

P_o = Ambient Pressure which is taken as reference pressure

The rupture causing unsteady flow in the pipeline is assumed to occur at the left end. As long as the pressure is sufficiently greater than the external pressure, the flow will be choked at the left end. The pressure and velocity at the right end is not affected until the

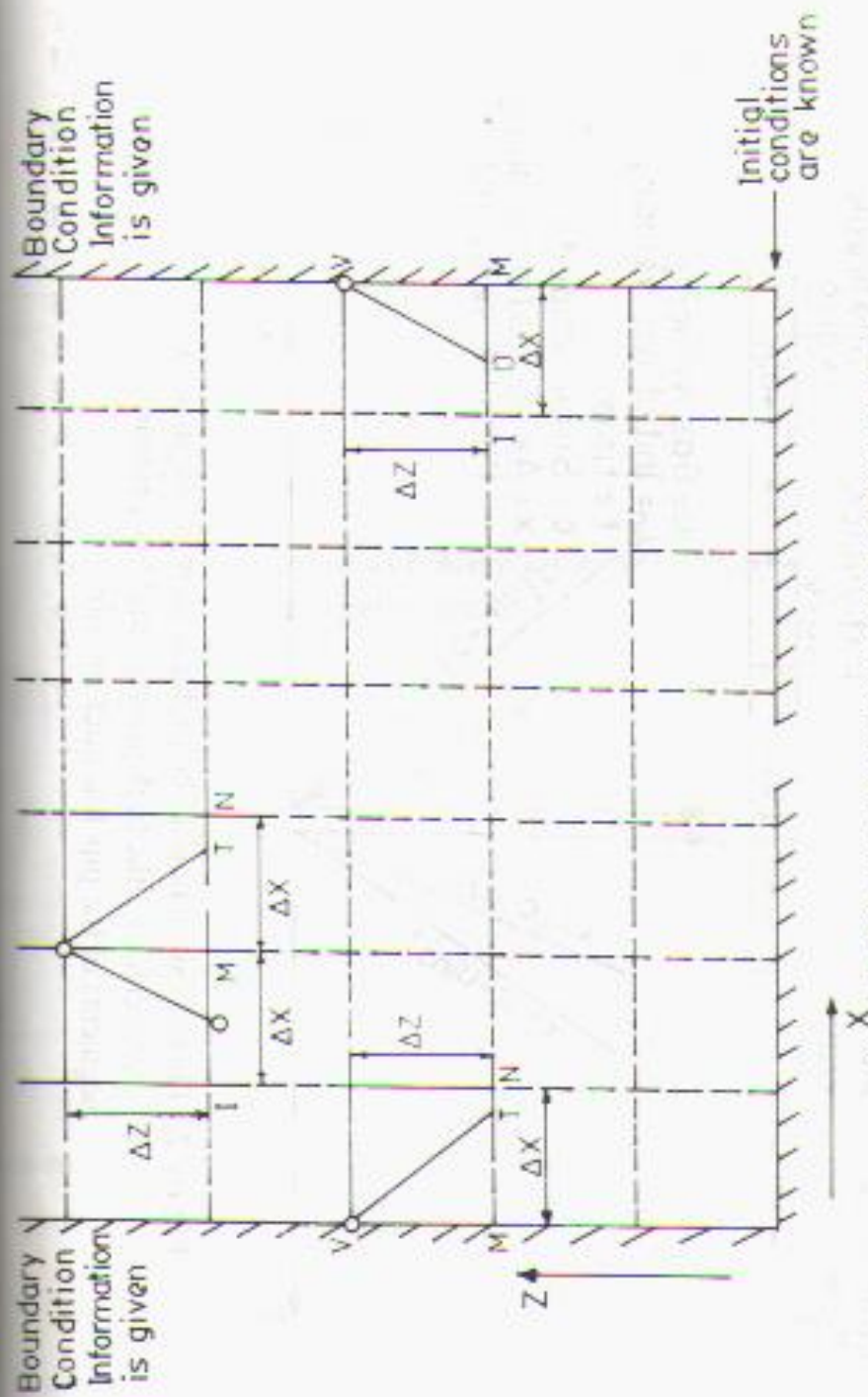


Figure 1: Characteristics reaching internal and boundary grid point for subsonic flow

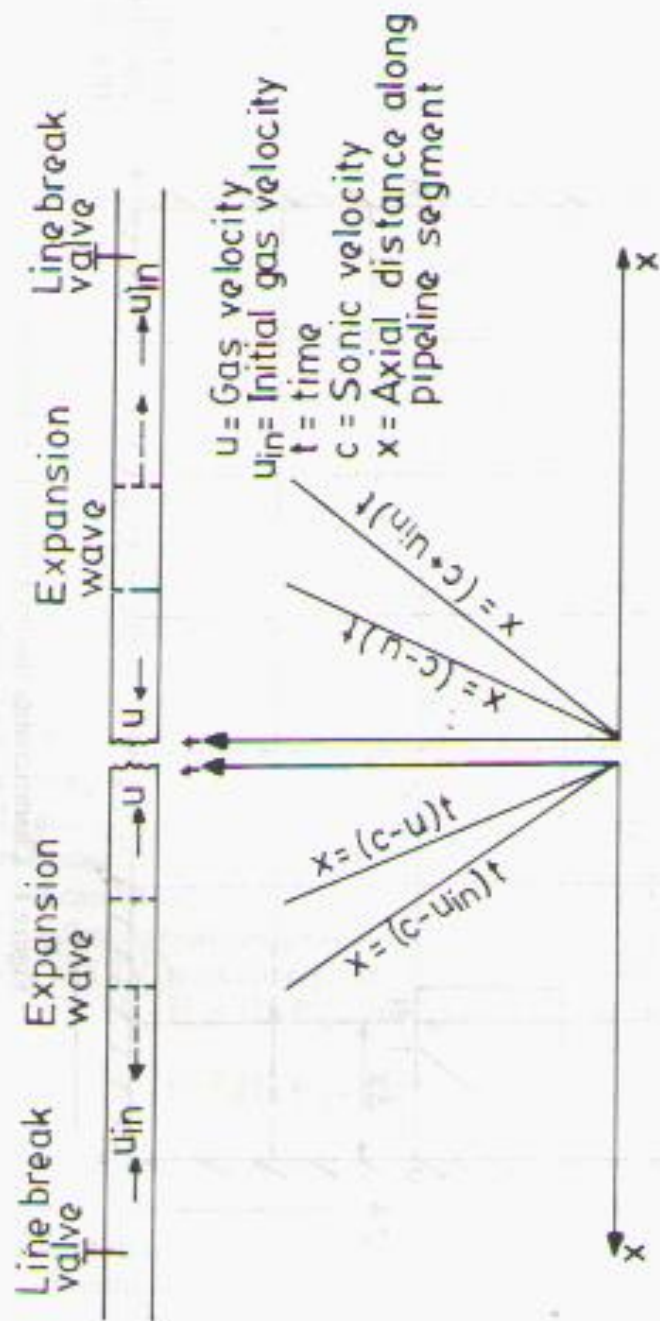


Figure 2: Physical situation of the problem showing expansion waves entering the high pressure and low pressure segments of the pipeline after rupture

TABLE 1:
INPUT DATA FOR THE COMPUTER PROGRAMME

Length of high pressure or low pressure segment of the pipeline,

$$l_0 = 24,725\text{m}$$

Diameter of pipeline, $d = 0.87\text{m}$

Specific gas constant of natural gas in the pipeline, $R = 417.4\text{KJ/K}_g\text{K}$

Ratio of specific heats of the natural gas $\gamma = 1.1492$

Friction factor, $f = 0.0025$

Ambient Pressure, $P_0 = 1\text{ bar}$

Ambient Temperature, $T_0 = 300.7\text{K}$

Initial condition:

Isothermal steady flow with inlet pressure and velocity at the left end of the 49.45km pipeline section

$$P_{in} = 67.225\text{ bar}$$

$$U_{in} = 1.3031\text{ m/s}$$

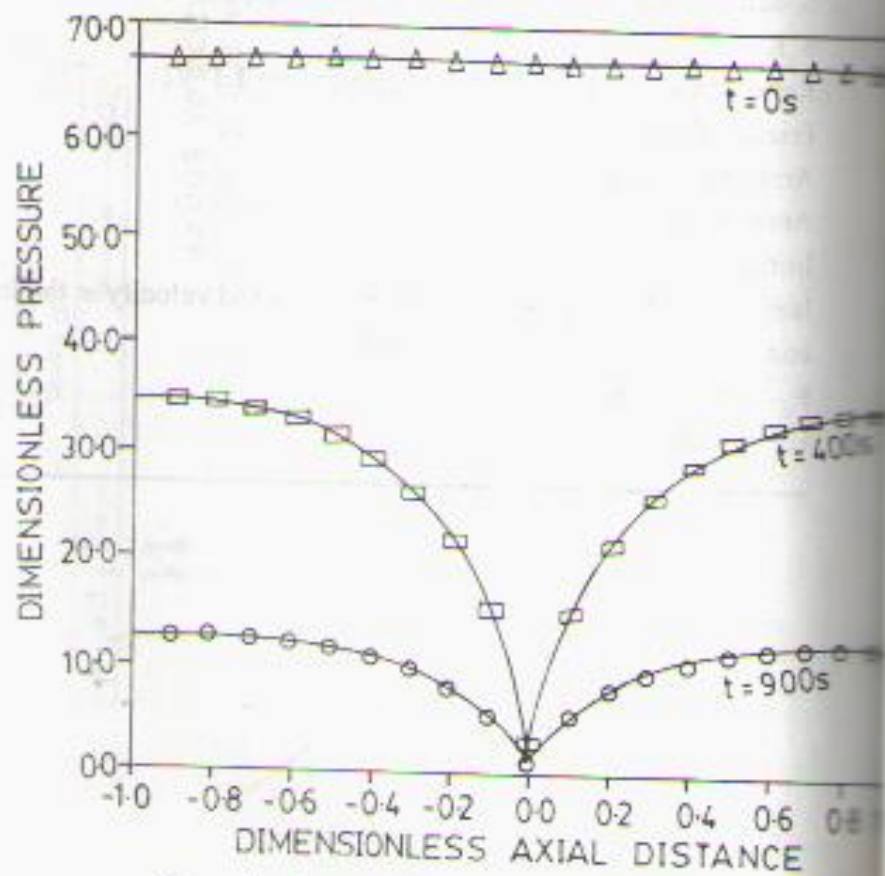


Figure 3: Pressure distribution in the high and low pressure segments predicted using 101 grid points.

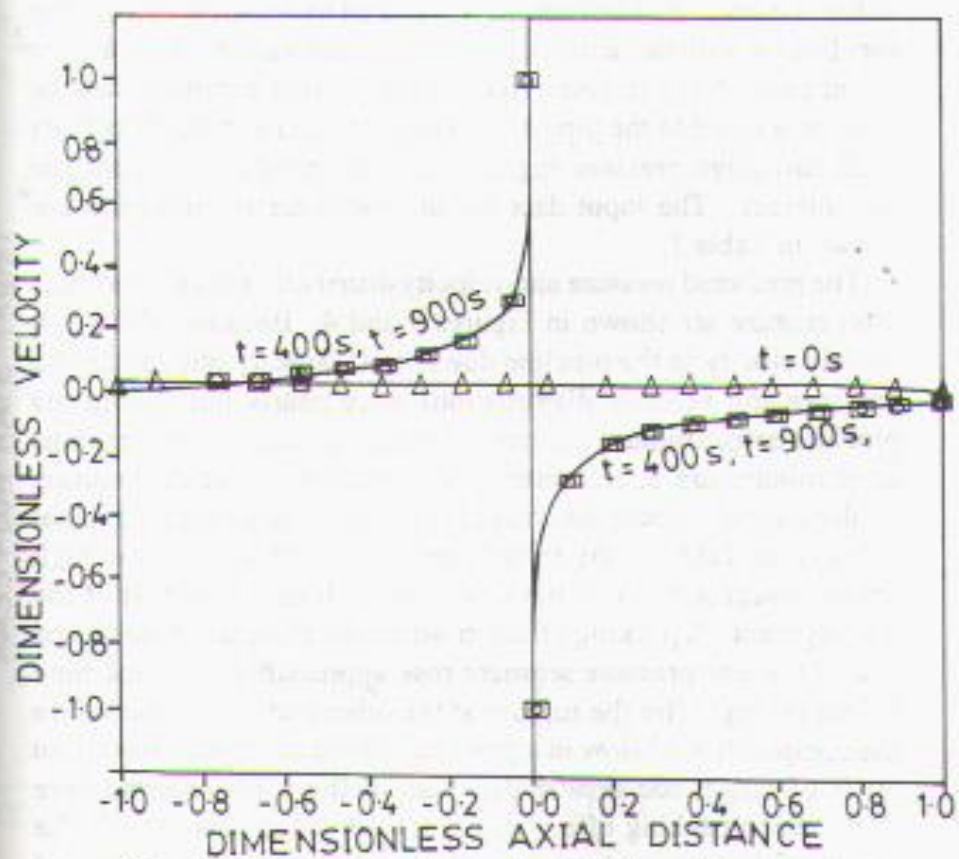


Figure 4: Velocity distribution in the high and low pressure segments, predicted using 101 grid points.

expansion wave which entered the pipeline at the left end when it ruptured, reaches there. The valve at the right end is then assumed to be shut instantaneously. More details of the mathematical model and the computer programme developed from it can be found elsewhere [7, 8].

The computer programme was applied to a section of Escravos - Lagos pipeline having a length of 49.45km with a line break valve at each end. The rupture is assumed to occur midway in the pipeline (at a distance of 24,725m from each end) to simulate the worst case of gas release. See Figure 2. It is assumed that the rupture is equal to the pipe cross-sectional area and the flow from each half (high pressure segment and low pressure segment) do not interact. The input data for the computer programmed are shown in Table 1.

The predicted pressure and velocity distribution at various times after rupture are shown in Figures 3 and 4. Because of the low initial velocity in the pipeline due to low capacity utilization, the pressure and velocity distributions were nearly uniform in the pipeline before rupture occurred. Hence the pressure distributions after rupture are approximately symmetrical about the rupture. With an initial velocity an order of magnitude higher than the initial velocity in Table 1, the initial pressure distribution in the high pressure segment would have been much higher than that of the low segment. A packing effect in which the pressure at the closed end of the low pressure segment rose appreciably for some time before falling, after the rupture at the other end, was observed in the computation of flow in a pipeline having an initial velocity an order of magnitude greater than that of the work reported here [7,8]. Such packing effect was not observed in this work. The results of the computation show that the pressure at the closed end of the low pressure segment decreased continuously with time as soon as the expansion wave reached there. The flows at the ruptured ends of the high and low pressure segments remained choked for about 1000s after the rupture because of the high initial pressure in the pipeline.

The mass flow rates out of the broken ends of the high and low pressure segments of the pipeline are shown in Figures 5 and 6.

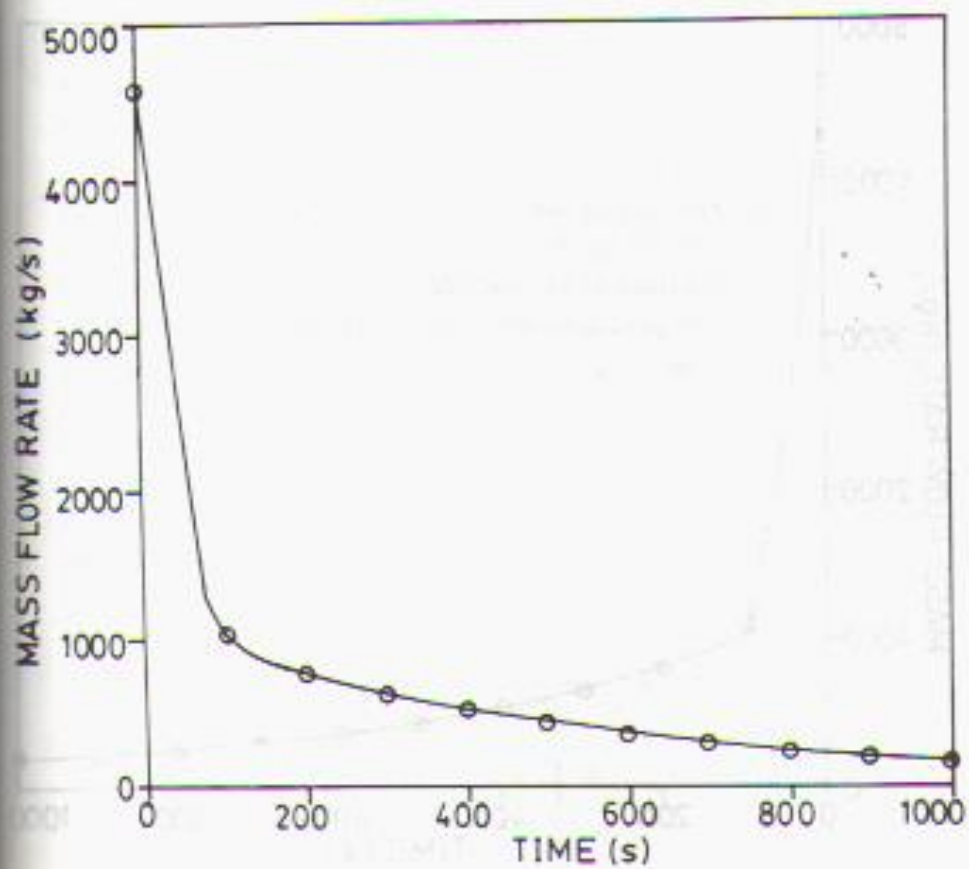


Figure 5: Mass flow rate at the ruptured end of the low pressure segment using 101 grid points.

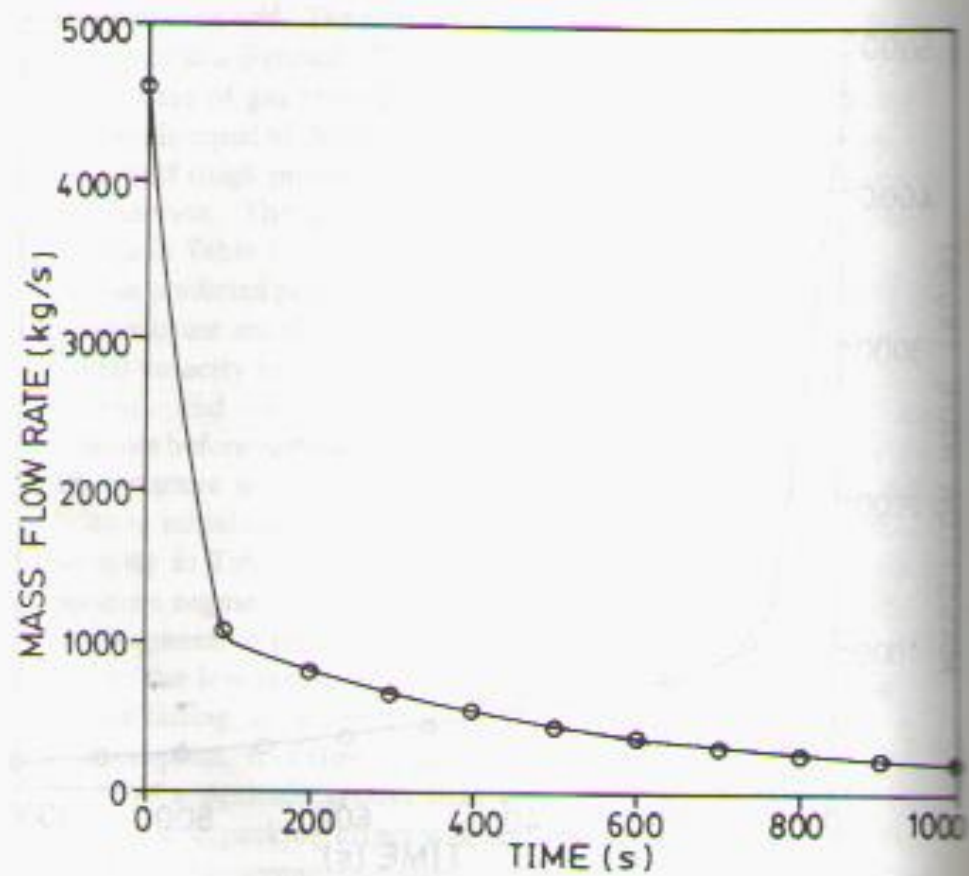


Figure 6: Predicted mass flow rate at the ruptured end of the high pressure segment using 101 grid points.

The variation of the total mass of gas released to the atmosphere, with time, from the two pipeline segments are shown in Figure 7. The mass flow rates out of the high and low pressure segments are approximately the same because of the low initial velocities in the pipeline causing the initial pressure to be nearly uniform. If the initial velocities had been higher, the mass flow rates out of the high pressure segment would have been appreciably higher than that of the low pressure segment. Due to the low initial velocities, the flows in the high and low pressure segments are almost like flow out of two long cylinders filled with high pressure natural gas having the same initial uniform pressure and initial velocity of zero. Even though the outflows remained sonic for so long, the mass flow rates out the pipeline segments fell very rapidly in the first 100 because seconds of the rapid fall of the pressure at the ruptured ends which caused the density to decrease rapidly.

A rough estimate of the space around the rupture where there is explosion hazard can be made by assuming the gas instantaneously disperses and mixes uniformly with air in all directions as it is discharged from the pipeline. The hazard zone will be a hemisphere with the rupture as its centre at ground level. The density of air at ambient pressure and temperature of 1 bar and 300.7K is taken to be constant in the hemisphere and the lower flammability limit of natural gas in air of 5% by volume [9] which gives the ratio of mass of air to mass of methane of 34.3 is used. The radius of the hemisphere of potential explosion hazard is given by

$$r(t) = \left[\frac{16.4 m_g(t)}{\rho_{air}} \right]^{1/3} \quad (6)$$

Where $m_g(t)$ = mass of natural gas released into the atmosphere up to time t

ρ_{air} = average density of ambient air.

The growth of the hemisphere of explosion hazard with time in the first one thousand seconds, obtained using the data in Figure 7, is shown in Figure 8. The results in Figure 7 and 8 show that about 11×10^3 kg of gas which is about 70% of the gas in the two pipeline

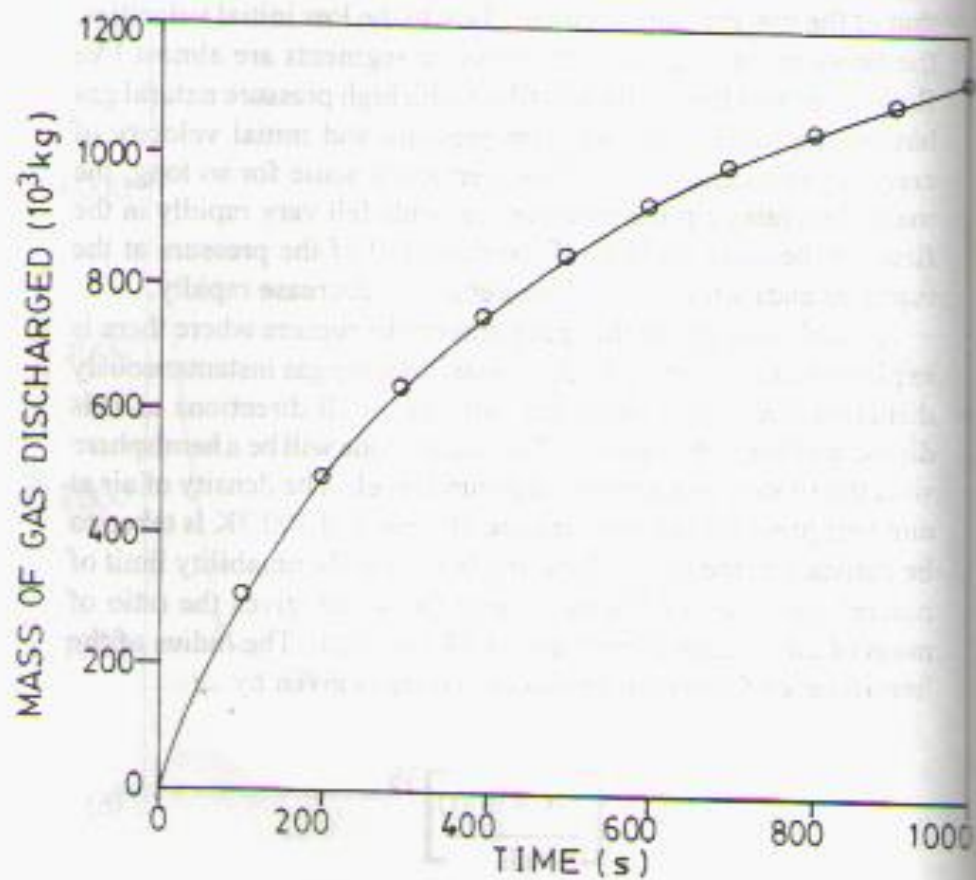


Figure 7: Variation of mass of natural gas discharged to the atmosphere with time, from the two pipeline segments.

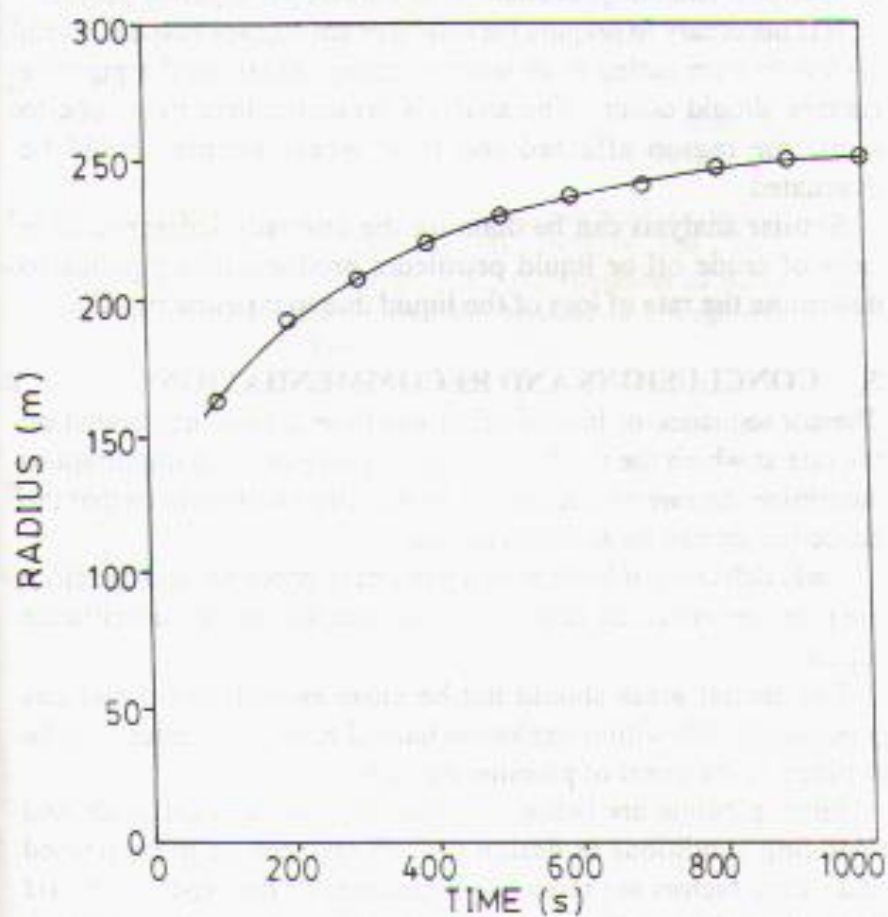


Figure 8: Variation of Radius of the hemisphere of explosion harzard with time.

segments initially, have been released to the atmosphere by 1000 seconds after the rupture and the distance from the rupture within which a flammable air-gas mixture can be present is 253m by this time.

The model is useful for choosing the appropriate spacing of line break valves on natural gas pipeline systems. It can also be used in environmental impact analysis of natural gas pipeline project.

It is necessary to prepare for effective emergency response with a view to eliminating or at least reducing casualties if a pipeline rupture should occur. The analysis presented here helps one to know the region affected and from where people should be evacuated.

Similar analysis can be done for the unsteady incompressible flow of crude oil or liquid petroleum products in a pipeline to determine the rate of loss of the liquid due to pipeline rupture.

5. CONCLUSIONS AND RECOMMENDATIONS

The consequence of loss of oil or gas from a pipeline depend on the rate at which the fluid is released. Therefore it is important to determine the rate of release and its variation with time so that the consequence can be assessed accurately.

Early detection of leaks from a pipeline is important and therefore the pipeline should be patrolled by ground and aerial surveillance teams.

Residential areas should not be close enough to oil and gas pipelines to fall within explosion hazard zone, if disaster is to be avoided in the event of pipeline rupture.

Since pipeline are being subjected to more critical loads and operating conditions as design procedures become more refined and safety factors are reduced, inspections of the pipeline should be conducted regularly so that the extent of damage or deterioration can be assessed to avoid catastrophic failure and ensure the safety of the pipeline system.

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