Crater Formation Limit a support to ROW and Risk Management

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ABSTRACT

For small leaks in gas pipelines we have observed that there is not always a crater formation, which leads us to question the crater formation limit and the behavior of the gas when it does not generate a crater. The formation of a crater occurs due to the high pressure of the fluid in the pipeline that upon release, through the hole, applies a force in the soil dragging it to the surface.

The main objective of this Join Industry Project was to determine the boundary between crater formation due to small leakage and no crater formation, represented by a change in the ground above the pipeline but without the presence of the crater. To meet this goal the INERIS-Institut National de l'environnement Industriel et des Risques conducted full scale experiments in its testing laboratory at Verneuil in Halatte, France. INERIS did the project developments hired by five companies: Air Liquid, GRTGaz, National Grid, Petrobras and TIGF.

1. INTRODUCTION

During 90's, some research laboratories developed several experiments looking for crater formation due to gas pipeline full bore rupture. At that time, the objective was to parametrize the phenomenon of crater formation characterized by large leaks and correlating some parameters such as: soil type, crater size, pipeline burial depth and angular position of the two pipe ends. The main goal was to understand the physics of crater formation and characterization of fireballs that may formed during rupture of high pressure gas pipelines, which are Major Accidents Hazard.

The main purpose of this JIP was to develop and validate a methodology to infer the boundary between crater formation and gas dispersion on the ground for high pressure pipelines. A model that can represent the behavior of leakage of small holes (holes from diameter 1 to 12mm) in high pressure pipelines is sought.

The physical mechanisms are somehow similar to jet grouting with a fluid-soil interaction. Depending on the type of soil the jet momentum push the soil for some distance, where we can identify, see figure 1:

1. Part of the soil returns and rises along the cement injection tube;
2. Part of the soil is eroded in the region near the injection (Zone 1);
3. Presence of infiltration region (Zone 2) due to soil permeability;
4. Fluid-soil interaction limit in Zone 3.

The extention of zones 1 (erosion zone) and 2 (infiltration zone) will depend on soil type (sandy or clay), fluid velocity and fluid discharge.

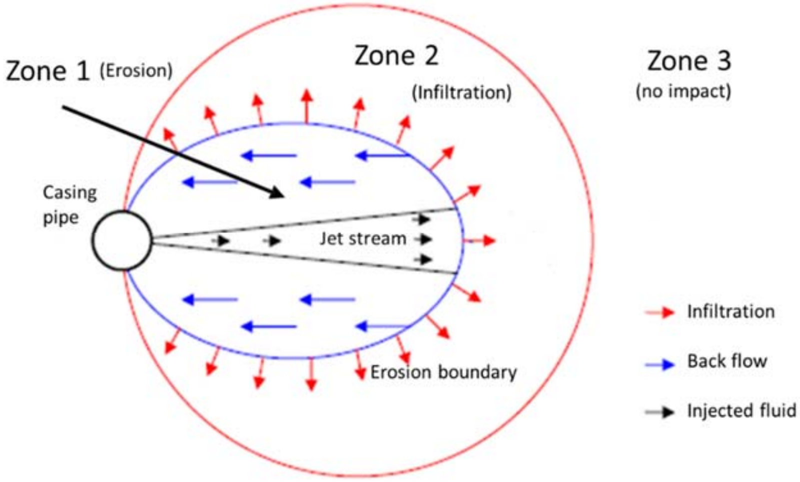

Fig.1 – Soil erosion mechanisms

On risk assessment for gas pipeline, a free gas jet is usually assumed on a pipeline hole and no question is made whether there will actually have a crater or just a gas permeation on the soil. Based on this research it is possible to understand a probable behavior for small holes.

2. EXPERIMENTAL SETUP

An area dedicated to these experiments was built on the INERIS laboratory, France. A scheme of the experiment site can be seen in figure 2. The gas leak was simulated through calibrated holes defined on each test and should represent a actual hole at a gas pipeline. In order to simulate a sudden leakage, the release setup is equipped with a rupture disc which shall burst when an upstream defined pressure threshold is reached, see figure 3.

A mockup representing 40" gas pipeline receives a 1 inch tube with a calibrated orifice and rupture disk. Two access covers have been cut in the pipe to allow handling of the inner discharge setup. This 1 inch tube can be equipped with any release hole up to 12mm diameter.

The fictive pipeline is connected to gas cylinders at 200bar, by means of piping and pressure control devices. By means of this template, it is possible to maintain the working pressure in the orifice during the experiment. Pressures and temperatures are measured at two locations inside the 1” tube: few cm upstream of the release orifice (P and T), and at the opposite end, near the gas connections to the racks (P and T tubes).

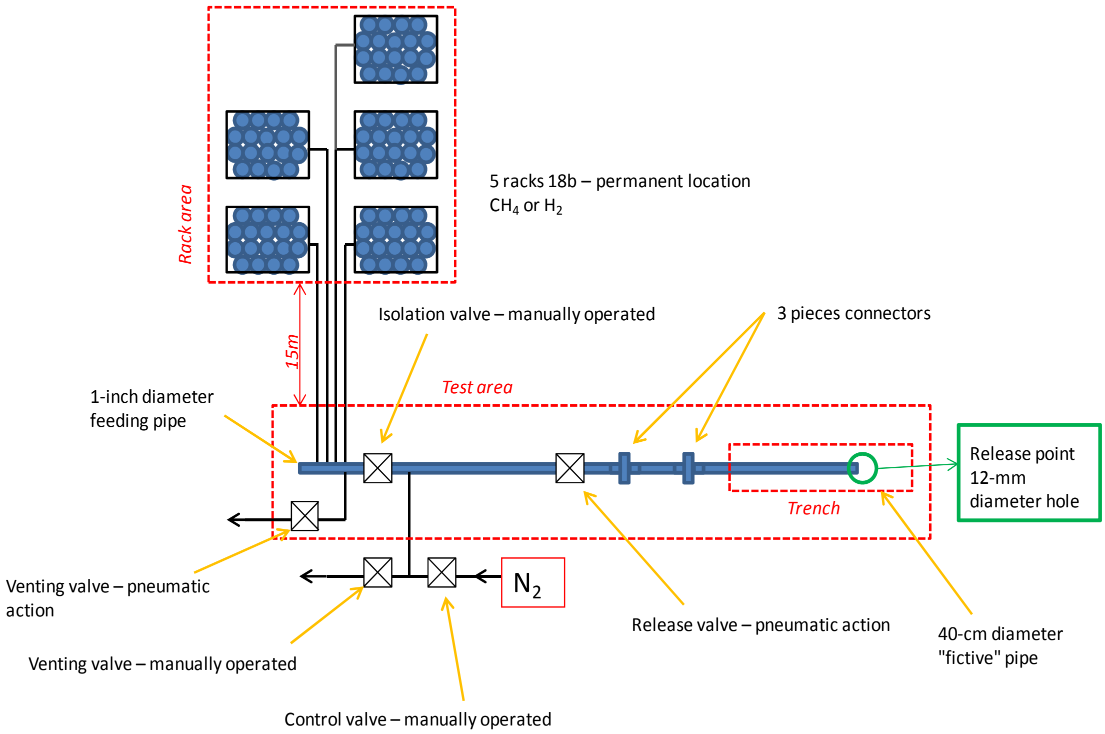

Fig.2 – Test area controls for leak experiments

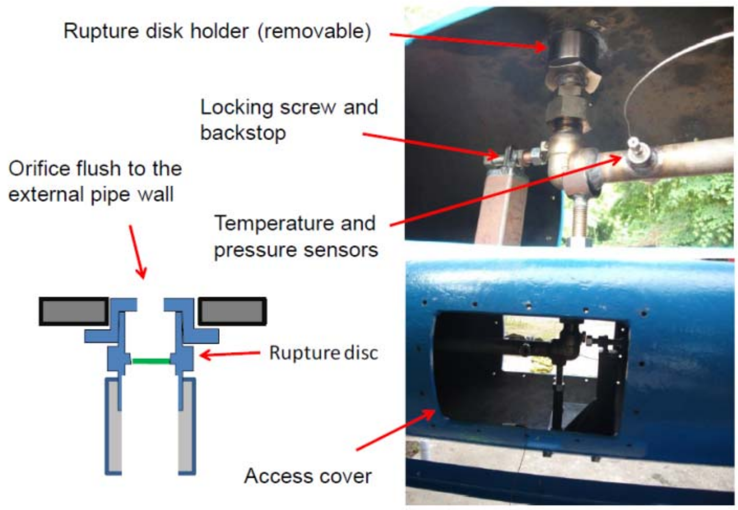

Fig.3 – Mock-up for pipeline leaks

Three high definition cameras are set around the experimental setup. One is used as a control device with a remote view in the control room. Another view is set at ground level, perpendicular to the pipeline axis on the trench, the last is set on a gantry at 3m high, to observed the trench in the axis.

3. SOIL CHARACTERIZATION

Depending on the experiment, if sandy or clay soil, the device that simulates the pipeline, see figure 4, is buried in sandy or clay soil, and being buried according to dimensions defined in the project, see figure 4.

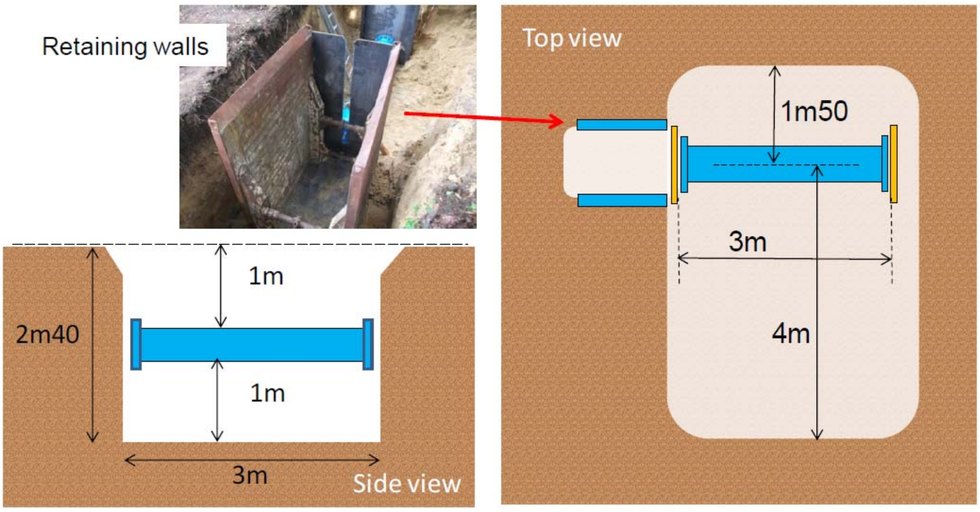

Fig.4 – Set up of the mock-up location on the test area

For each experiment, the soil (clay or sandy) was compacted according to a procedure standardized by INERIS, the main steps being as follows:

1. Clean the previous test trench;
2. Apply three compacted soil layers up to the height of the pipeline support;
3. Gas sensors and tubes are connected;
4. Rupture disc is set and angle of leak set;
5. Apply the other layers of soil (20cm / layer);

Soil compaction is controlled by penetrometer in each layer deposited, with level of compaction Q4, according to NF P98-331 (2205). The soils used in this study were classified according to the ASTM USCS-Unified Soil Classification System and equivalent French Standard NFP 11 300, see table 1.

Tab.1 – Soils classification for experiments (US and France Std)

Soil Class	**USCS**	**NFP 11 300**
Sand soil	**SP-SM** : Poorly graded sands, gravelly sands, little or no fines - Silty sands, sand-silt mixtures	B2
Clay soil	**CL**: Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	A2

6. LEAK CHARACTERIZATION

The pressure and temperature data were monitored in the leaks near the hole locations, or better near the rupture disk, as indicated in figure 3. These sensors allow to verify the stability of the temperature and pressure during the simulation of leakage, as well as to estimate discharge through the orifice.

The discharge model has been validated by flow measuring equipment, named DECALOR. This validation process is necessary to recognize the loss of charge by the gas supply piping and accessories.

Based on the installation implemented by INERIS, for the crater formation experiments, 20 tests were performed according to the following scope:

1. Leakage of: methane, hydrogen and nitrogen (discharge model verification);
2. Gas pipeline pressures: 15 to 120 bar;
3. Hole diameters: 1 to 15 mm;
4. Leak directions: upward, downward and horizontal;
5. Types of soils: sandy and clay.

7. EXPERIMENT RESULTS

The test program had 20 experiments, the outcomes are presented on table 2, and it should be noted compatible soil behaviors along the experiments, depending on the soil, hole size and pipeline working pressure.

Typical soil behaviors are:

1 No movement - without apparent displacement of the soil,
2 Crater formation - with soil expulsion and gas release into the atmosphere;
3 Mixed - initial effect of soil movement, followed by formation of crown delimited by cracks, with diffusion of gas through soil and cracks;
4 Uplift - noticeable effect of soil movement but there is no crater formation.

As observed in table 2, no crater was formed in clay soil, even at the higher working pressure according to test #14 or for the larger diameter according to test #16, this behavior derives from the greater plasticity of the clay. For crater formation in clay soil there will be a need to increase the pressure or diameter of the leakage, which was not performed due to the limited amount of experiments developed.

Observing all tests done we can conclude about crater formation for gas pipelines:

- For pressures that created crater due leaks on upward direction, no crater formation is observed for other leaks directions (horizontal or downward);
- No crater formation due to 5mm holes on pipelines up to 120 bar installed on sandy or clay soil;
- No crater formation due to 9mm holes in pipelines up to 75 bar on sandy soil;
- No crater formation due to 12mm holes in pipelines up to 36 bar on sandy soil.

Tab.2 – Soil effects due to pipeline leakage

# Test	Soil	Release direction	Gas	Release diameter (mm)	Pressure (bar)	Descarga incial (g/s)	Main effects
3	Sandy	Upward	CH4	12	62	1280	crater
6			CH4	12	47	940	crater
10			H2	12	46	310	crater
7			CH4	12	36	730	mixed
9			CH4	12	18	355	uplift
11			H2	12	17	120	uplift
4	Sandy	Downward	CH4	12	56	1110	uplift
5		Horizontal	CH4	12	56	1090	uplift
14	Clayed	Upward	CH4	12	78	1300	uplift
15			CH4	12	63	1240	uplift
13			H2	12	48	283	uplift

From the information in table 2, we can verify that there is a correlation of the working pressure of the pipeline and the size of the leak hole in upward direction, for sandy soils that are less plastic. So, as working pressure increases there is a crater formation tendency. The data are valid for burial depth of the test pipeline (1m), hole in the upward direction and sandy soil.

8. CONCLUSION

It was investigated the crater formation limit resulting from small leaks in gas pipelines, in order to verify the limits of recognition of these leaks by ROW team as well giving support to risk analysis for gas pipelines. To achieve this goal, INERIS has developed an experimental template for reproduction of gas pipeline leaks, in real size.

The main evidences were:

- Direction of the leak: pressures below 56 bar do not generate a crater, except if the orifice is in upward direction;
- Low pipeline pressures: from pressure lower than 56 bar (till 18 bar) just a soil uplift were obtained;
- Type of gas: there is no significant difference between hydrogen and methane in crater formation;
- Soil type: there is a significant difference between the clay and sandy soils that defines whether there will be crater formation. It was observed that soil moisture influences its resistance and plasticity. For clay soil, crater formation does not occur within the orifice range of this study.

More investigations have to be done in order to propose rigorous and robust correlation of the working pressure and leakage orifice which indicates formation of a crater.

9. REFERENCES:

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[3] D Houssin-Agbomson, G Blanchetière, D McCollum, C Saint-Macary, Renato F. Mendes, D Jamois, M Barbalat, A Foissac, T Lubet. Consequences of a 12-mm diameter high pressure gas release on a buried pipeline. Experimental setup and results. Submitted to Journal of Loss Prevention in the Process Industries, Submitted on July 2016.