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Gas migration in soil from a distribution network leakage: an experimental and numerical study to assess time and spatial scales

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ABSTRACT

Gas distribution networks are submitted to various aggressions and loads that may sometimes lead to involuntary leaks: external interference, corrosion, sealing issues, etc. Gas may therefore be released and may follow different paths below ground, through cracks, along pipelines or below the road surface. The objectives of this work are to quantify buried gas leak flow-rates and to determine the extension of the flammable gas volume, and the time needed to reach a steady state.

In the framework of a GERG (Gas European Research Group) project with Gas Natural, National Grid, E.ON Technologies and GDF SUEZ as partners, realistic configurations that are representative of gas distribution networks in Europe were defined in terms of pipe diameters, burying depths, structure of urban near-surface soils, etc. Then, based on the previous findings, GDF SUEZ developed an experimental method to quantify buried gas leak flow-rates as well as time and spatial scales of gas migration in soil. A test rig of 9.5x8.5x2.7 m^3 filled with compacted sand was set up, and methane was injected at 1 m depth. Two leak diameters (1 mm and 5 mm), and several inlet pressures varying from 40 $mbar_g$ to 15 bar_g were tested. Resulting flow-rates ranged between 0.2 L(n)/min and 24 L(n)/min. Gas concentrations were measured all around the sand volume, thanks to numerous vacuum probes. For all experimental cases, a steady state was reached, which means that flammable gas volume does not increase without bounds, due to the existence in this case of a balance between lateral spreading and buoyancy.

The large amount of experimental data acquired during this campaign first allowed to validate a formula linking the gas leak flow-rate to known soil characteristics. This formula mainly depends on the inlet pressure, the leak diameter, the soil permeability and the Forchheimer coefficient. These two last parameters directly depend on the type of soil but are not well referenced in the literature. Thanks to the instrumentation developed within this project, it is now possible to estimate them by performing simple instrumented injections of compressed air below the ground surface.

Then, numerical codes were compared to the experimental results to assess their ability to simulate gas migration in soil. TAGS, which is a 3D code developed by GDF SUEZ, OSAKA GAS and TOKYO GAS in the 90's and after only by GDF SUEZ, shows satisfactory results. It is able to properly predict the time constants of the phenomenon and it is conservative in the calculation of the flammable gas volume for the simple experimental set-ups explored until now. In parallel, other codes have been tested, as ANSYS CFX, with encouraging results. In order to qualify numerical simulation codes on more complex and more realistic experimental set-ups and to produce additional results about weather and soil influence, the test equipment was transferred to a test field in Germany. Here, another test series took place and data from a rural gas pipeline situation as well as from a scenario with service lines close to cellar walls were acquired.

1 INTRODUCTION

Gas distribution networks are submitted to various aggressions and loads that may sometimes lead to involuntary leaks: external interference, corrosion, sealing issues, etc. Gas may therefore be released and may follow different paths below ground, through cracks, along pipelines or below the road surface. Gas migration in soil is a physical phenomenon less known than atmospheric dispersion. The objectives of this work are to quantify buried gas leak flow-rates and to determine the extension of the flammable gas volume, and the time needed to reach a steady state.

In the framework of a GERG (Gas European Research Group) project with Gas Natural (Spain), National Grid (United Kingdom), E.ON Technologies (Germany) and GDF SUEZ for GrDF (France) as partners, realistic configurations that are representative of gas distribution networks in Europe were defined in terms of pipe diameters, burying depths, structure of urban near-surface soils, etc. Then, based on the previous findings, GDF SUEZ, as project leader, has developed an experimental method to quantify buried gas leak flow-rates as well as time and spatial scales of gas migration in soil in 2011-2012. Material was set up in three different facilities between 2012 and 2013 to acquire a large amount of data. These results were used to test the ability of three CFD numerical codes to simulate the gas migration in soil.

2 TYPICAL GAS NETWORK AND LEAK CONFIGURATIONS IN URBAN SOILS

A survey was performed on different typical gas networks and leak configurations on urban soils, carried out by GDF SUEZ among the GERG members participating to the project. The objectives of the survey were:

- To share knowledge about underground leak configurations in different European countries;
- To obtain information about pressure ranges, leak sizes, typical network construction configurations, soil types and associated typical building foundations;
- To define the configurations representative of the European countries to be studied in the experimental phase.

The survey compares the urban network configuration in the gas industry representing typical situations of the respective countries: Gas Natural, E.ON Technologies, National Grid and GrDF. It is divided in three main parts:

- network construction characteristics (main gas network pipe materials, trenching and excavation techniques, preferential paths, …),
- parameters of gas leak (diameter, pressure, flow-rate, causes of the leak),
- typical trench section.

2.1 Main materials for gas network pipelines

Table 1 shows the main materials for gas pipelines on distribution networks for the GERG members. For main pipes of the distribution network, the most used material among GERG members is PE (between 50% and 82% depending on pressure). For E.ON, in the case of pressures less than 1 bar, polyethylene is the most used material (80% PE / 20% steel). For higher pressures (> 1 bar), PE and steel are uniformly used. For National Grid, it depends also on pressure. PE is used up to 7 bar with a percentage of 53%, cast or ductile iron and steel are used up to 2 bar in small percentage (between 3 and 6%). For Gas Natural and GrDF, the main material is PE for all pressures (between 68 and 82%).

2.2 Trenching and excavation techniques

It can be noticed that all companies consider the same order of dimensions for trenchs, depth around 1 m and width between 0.3 and 1 m (around 0.3 m used by Gas Natural and GrDF, while a value of 1 m is used by E.ON and National Grid). Several types of trench were identified as a function of environmental conditions. Different materials, layers and degrees of compaction are also used for trench construction increasing the degree of complexitity for the definition of few representative configurations. The same kind of materials (sand, concrete or backfill, pavement, bitumen) are used by the companies with a reference to the optimum proctor or to the local authorities request for compaction characteristics.

Table 1. Main materials for gas pipelines on distribution networks for the GERG members

		Gas Natural (Spain)	GrDF (France)	E.ON Ruhrgas (Germany)	National Grid (United Kingdom)
Materials	**Main pipes**	82% PE 15% steel 3% other	68% PE 28% steel 4% other	P>1 bar: 50% PE 50% steel P<1 bar: 80 % PE 20% steel	53% PE (up to 7 bar) 3% Cast Iron (up to 2 bar) 6% steel/ductile iron (up to 2 bar)
	Service pipes	98% PE 2% steel	-	80% PE 20% steel	67% PE 25% Steel 8% PE + steel

2.3 Release characteristics on distribution network

The causes initiating leaks, the release diameter and the flow rate observed by each company are specified in Table 2. Regarding causes initiating leaks, it can particularly be noticed that most of the companies consider "external interference" as an important threat. For GrDF and National Grid, the percentage of external interference causing leaks is between 68% and 50%. For E.ON Ruhrgas, this percentage is higher in the case of PE (about 80%) and 20% in the case of steel. However, for Gas Natural, "external interference" is the cause of 15-20% of leaks, but more important than corrosion (0.5%) or material defect (1%); 78-83% of the leaks are due to "other" causes, which might be interpreted in different ways.
Concerning leak diameter, only Gas Natural and GrDF gave this information. For both companies, a pinhole of less than 5 mm is usually observed. In the case of GrDF, it is possible also to find slots of 5 cm x 1 mm. The estimated flow rate of a leak on distribution networks is a also a parameter which is difficult to determine. E.ON Ruhrgas finds values between 0 and 100 L(n)/h with a mean value of 20 L(n)/h.

Table 2. Release characteristics on distribution pipelines of the GERG members

	Gas Natural	GrDF	E.ON Ruhrgas	National Grid
Initiating leak causes	Corrosion: 0,5% Material default: 1% External Interference: 15 – 20% Other: 78 – 83%	Corrosion: 11% Material default: 5% External Interference: 65 % Other: 19%	Corrosion: Steel > 90% Material default: PE > 23% External Interference: Steel < 10% PE < 80%	Corrosion: 30% Material default: < 1% External Interference: 50% Fractures/broken iron: 20%
Size leak diameter	< 5 mm	Pinhole: 2 - 5 mm Slot: 5 cm x 1 mm	*unkown*	*unkown*
Leak flow rate	unkown	unkown	0 – 100 L/h (mean value: 20 L/h)	unkown

2.4 Representative configurations of GERG members to be studied experimentally

Resulting from the survey presented previously, it was decided among GERG companies to limit the number of experimental tests to the configurations described in Table 3.

Table 3. Representative configurations deduced from the GERG survey, to be studied experimentally

Diameter of the pipeline (mm)	Pressure (bar_g)	Leak diameter (mm)	Depth of burial (m)
100	0.04	1 (high pressure) 5 (low pressure)	0.8
	0.4		
	2		
	4		
	16		

3 AN EXPERIMENTAL CHARACTERIZATION OF THE GAS MIGRATION IN SOIL

3.1 A device specially designed for the characterization of the gas migration in soil

To be able to assess time scales and typical distances of the gas migration in soil phenomenon, a device was specially designed (Figure 1). It is first constituted by an “injection line” with:

- an injection plate which measures the gas flow-rate (from 0.04 to 30 L(n)/min) and regulates the pressure (from 0 to 20 bar_g);
- a rod driven into the ground thanks to a heavy hammer, with a horizontal leak orifice (1 or 5 mm depending on the endpiece). Pressure sensors are adapted to the rod and used for the regulation. The temperature of the gas injected is measured.

The second part, which is called the “measurement line”, allows the punctual measurement of the gas concentration in the soil around the leak with:

- 69 measurement probes which collect gas samples in the soil by suction. The probes can be driven at 2 m depth. They were placed in areas of interest, without disturbing the gas migration thanks to their low diameter and the low flow used for the sampling;
- 23 sensor plates by which the gas is analyzed with an IR sensor.

This device was designed so that it can be easily moved. It can be set up in situ in a few days, using only a gas and power supply. The measurements are recorded, and it is fully autonomous. The reliability of the device was verified: a test can last several days without any anomaly. INERIS (French National Institute for Industrial Environment and Risks) gave a positive opinion on the relevancy of the protocol defined by GDF SUEZ.

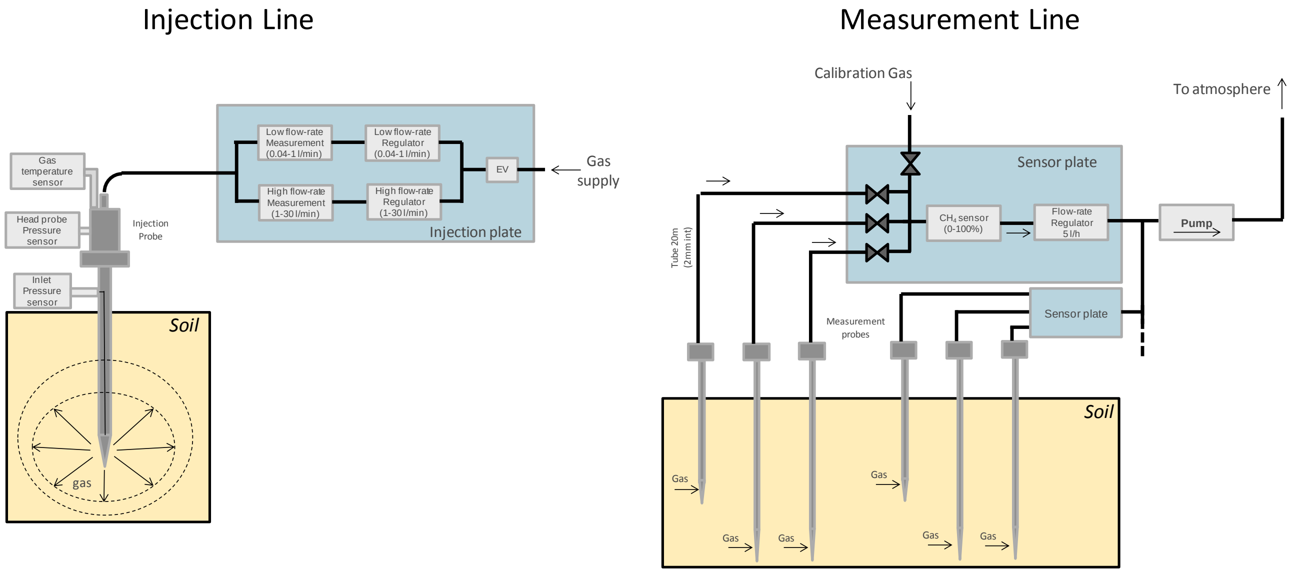


Figure 1. Views of the Injection and Measurement Lines designed for the characterization of gas migration in soil.

3.2 Gas migration in a homogeneous soil: a steady state is reached after several hours

The first campaign of tests was performed on a homogeneous soil in 2012, at GDF SUEZ, in an area specially prepared for these types of experiments (Figure 2). The test rig is a parallelepiped of 9.5x8.5x2.7 m^3. The limits of the test rig have been proofed thanks to a cover. The boundary conditions of the experiment are therefore well known: walls everywhere except for the interface between sand and air.

Figure 2. Pictures of the GDF SUEZ homogeneous test rig with the device set up for the characterization of the gas migration in soil.

The test rig is filled with Cuise sand, which has been uniformly compacted, in order to reach a compaction objective similar to the ones surrounding gas distribution pipelines. Granulometry of the sand is distributed between 40 and 1000 µm. The porosity of the medium is assessed at 32%.

In order to assess the soil permeability and its Forchheimer's coefficient, the following equation was used:

$$Q_m = \frac{6\pi\mu R_{eq}^2}{k\beta}\left[-1+\sqrt{1+\frac{k^2}{\mu^2}\frac{2\beta M}{3R_{eq}RT}(P_{inj}^2-P_{atm}^2)}\right] \tag{1}$$

With Q_m the mass flow-rate in soil, k the permeability, β the Forchheimer's coefficient (taken into account for high gas velocities), M the molar mass, R the ideal gas constant, T the temperature, μ the dynamic viscosity, P_{inj} the absolute injection pressure, P_{atm} the ambient pressure, and R_{eq} the equivalent radius which is defined by $R_{eq} = {R_{leak}}/{2}$.

Gas was injected in the GDF SUEZ test rig for various inlet pressures, and the flow-rates resulting were measured. Comparing the experimental data and the equation (1), the following values of permeability and Forchheimer's coefficient have been assessed (Figure 3): k=2.3 D and β=9e5 m^{-1}.

Six configurations, resulting from the survey presented in 2.4, were studied in the GDF SUEZ test rig (Table 4). For all of them, the symmetry in the gas migration was verified, so that the problem can be considered as two-dimensional. Flow-rates vary from 0.16 to 24.4 L(n)/min.

Table 4. Matrix of the configurations studied in the GDF SUEZ test rig

Test	Leak diameter (mm)	Inlet pressure (bar_g)	Inlet flow-rate (L(n)/min)
1 mm – 40 $mbar_g$	1	0.04	0.16
1 mm – 400 $mbar_g$	1	0.4	0.95
1 mm – 2 bar_g	1	2	3.8
5 mm – 400 $mbar_g$	5	0.4	6.4
1 mm – 4 bar_g	1	4	6.7
1 mm – 15 bar_g	1	15	24.4

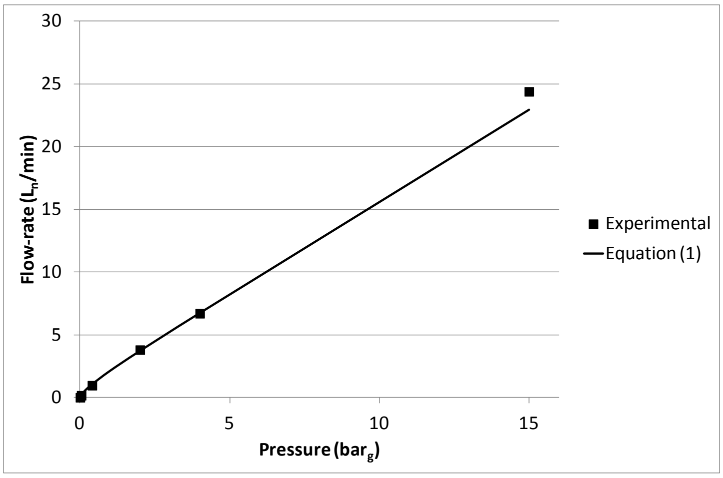
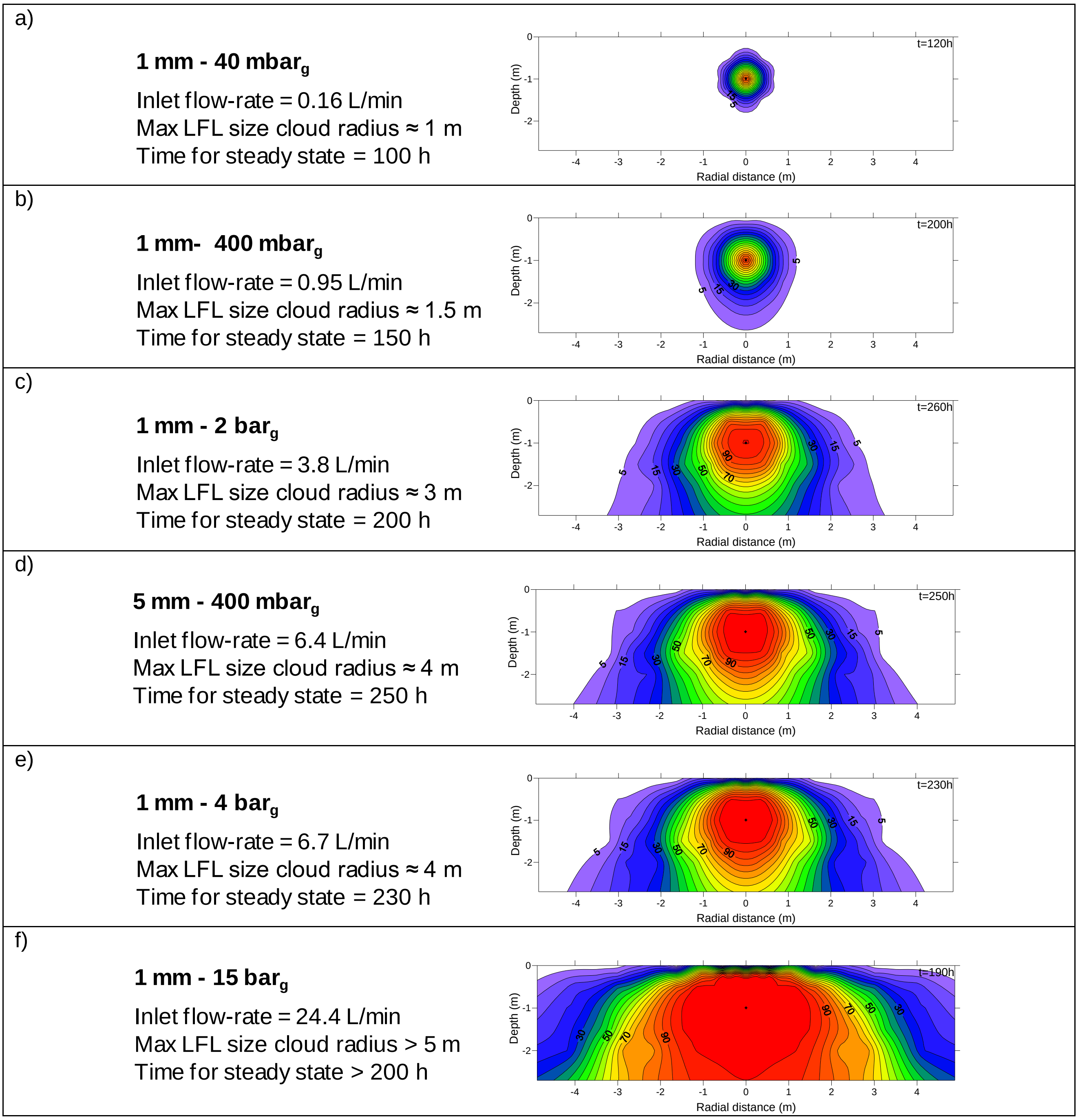


Figure 3. Assessment of permeability and Forchheimer's coefficient of the GDF SUEZ test rig: comparisons between experimental data and equation (1) lead to k=2.3 D and β=9e5 m^{-1}

A steady state in the measurement of gas concentration can be reached. This steady state is obtained when the inlet flow-rates equals the exchanges between air and gas: concentration does not evolve anymore. Injection can last several days before reaching the steady state, but it depends on the flow-rate: the higher the flow-rate is, the higher the time to steady state is. For the configuration 1 mm – 40 $mbar_g$ with a flow-rate of 0.16 L(n)/min, time to steady state is about 100 h. For the configuration 1 mm – 4 bar_g with a flow-rate of 6.7 L(n)/min, time to steady state is more than 200h. Figure 4 shows the gas volume with the concentrations measured experimentally in the GDF SUEZ test rig when steady state is reached.

The lower concentrations close to the top limit can be explained by the exchanges between air and gas at the interface. A dilution occurs in the first layers of the test rig.

INERIS confirmed the consistency of the results. These data will be used to validate numerical codes and to develop empirical models.


a)

1 mm - 40 $mbar_g$

Inlet flow-rate = 0.16 L/min
Max LFL size cloud radius ≈ 1 m
Time for steady state = 100 h

b)

1 mm- 400 $mbar_g$

Inlet flow-rate = 0.95 L/min
Max LFL size cloud radius ≈ 1.5 m
Time for steady state = 150 h

c)

1 mm - 2 bar_g

Inlet flow-rate = 3.8 L/min
Max LFL size cloud radius ≈ 3 m
Time for steady state = 200 h

d)

5 mm - 400 $mbar_g$

Inlet flow-rate = 6.4 L/min
Max LFL size cloud radius ≈ 4 m
Time for steady state = 250 h

e)

1 mm - 4 bar_g

Inlet flow-rate = 6.7 L/min
Max LFL size cloud radius ≈ 4 m
Time for steady state = 230 h

f)

1 mm - 15 bar_g

Inlet flow-rate = 24.4 L/min
Max LFL size cloud radius > 5 m
Time for steady state > 200 h

Figure 4. View of the gas concentration in the GDF SUEZ test rig when steady state is reached, for all configurations studied.

3.3 Experiments in a rural soil: gas migrates further under an impermeable surface

Instrumentation designed for the gas migration in soil study and presented in 3.1 has been transferred in April 2013 to Emsbüren (Germany), to be set up on the E.ON rural test rig (TF2). In this test rig, a 3 m length pipeline (400 mm diameter) is positioned at 80 cm depth. A trench had to be dug to place this pipeline, modifying the soil properties around. Moreover, in order to study the influence of the top boundary condition, a tarp has been placed on the half part of the test rig (Figure 5). The injection of gas has been performed in the centre of the test rig, over the existing pipeline, at 60 cm depth.

Using the equation (1), permeability of the methane has been assessed at 17 D at the injection point and Forchheimer's coefficient at 10^5 m^{-1}. Far from the injection, the permeability is about 10 D, and Forchheimer's coefficient is 5 10^4 m^{-1}.

Porosity has not been measured, but from the nature of the soil (black sand), it can be estimated at 30% in the original soil and at 40% in the trench. Water saturation has been assessed at 50%. The ground water level in the soil, about 1.3 m depth, is considered as a horizontal wall boundary condition for the gas.

Methane injection was performed at 60 cm depth at the centre of the test rig. Three configurations have been tested (Table 5). Many difficulties occurred due to heavy rain falls.

Table 5. Matrix of the configurations studied in the rural test rig of E.ON (TF2)

Test	Leak diameter (mm)	Inlet pressure (bar_g)	Inlet flow-rate (L(n)/min)
1 mm – 220 $mbar_g$	1	0.22	3.5
1 mm – 3 bar_g	1	3	10
1 mm – 4 bar_g	1	4	17

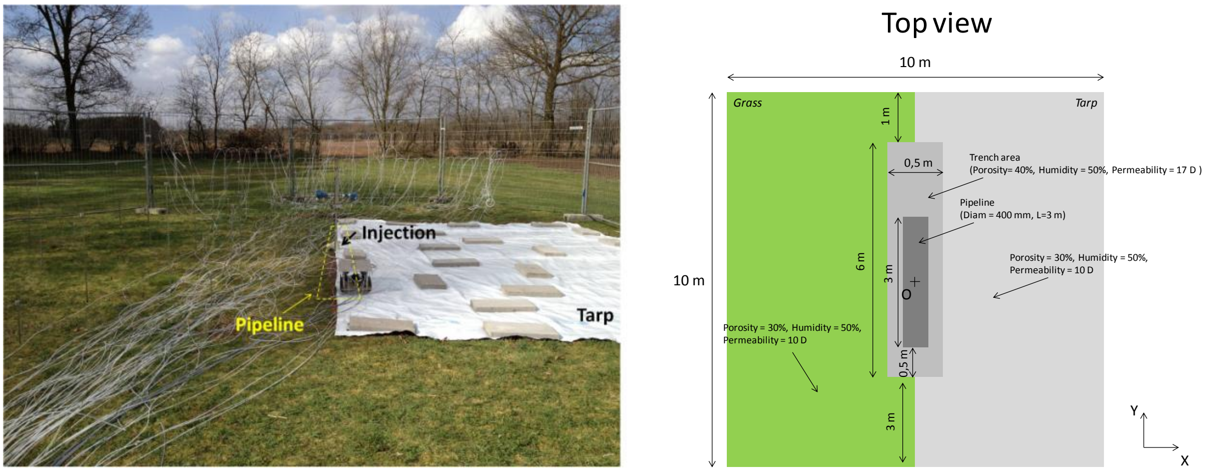


Figure 5. Picture of the TF2 rural test rig in the configuration for gas migration in soil study

It can be noticed that the influence of the boundary condition is mainly seen between the surface and 50 cm depth (Figure 6). It is in this area that exchanges between air and methane can occur. Therefore, on the tarp side of the test rig, if there is no exchange between air and methane, it entails a higher concentration of the methane close to the surface. Indeed, due to its low density and buoyancy effects, gas is going to rise until the surface.

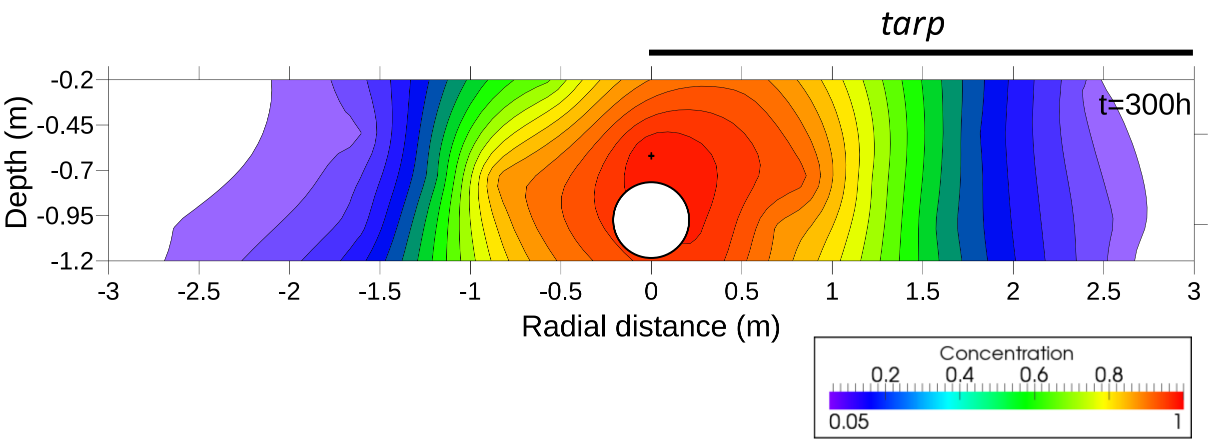


Figure 6. View of the experimental gas concentration measurements when steady state is reached in the TF2 test rig for the configuration 1 mm – 220 $mbar_g$: concentrations are higher on the tarp side

3.4 Injection of gas in an urban soil: gas follows the contour of the pipelines

The urban test rig TF3 of E.ON is a test rig with three 5x5 m^2 compartments whose characteristics are different (Figure 7). These compartments are separated by walls of 1 m depth. In each compartment, a gas pipeline (110 mm diameter) is positioned at about 80 cm depth. In the middle compartment, there are three service lines: a phone line (20 mm diameter), a drinking water line (50 mm diameter) and a waste water line (70 mm diameter).

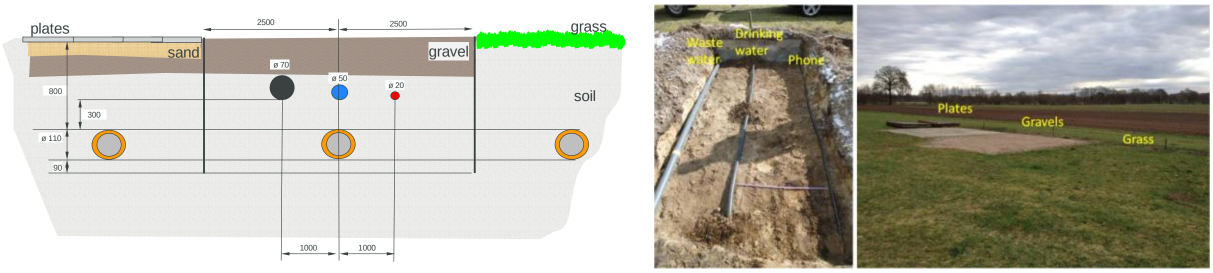


Figure 7. View and picture of the urban test rig of E.ON: gas injection was performed in the middle compartment to assess the influence of the buried pipelines

The soil properties are assumed to be homogeneous in the TF3 test rig. Using the equation (1), permeability of the methane has been assessed at 3 D in the middle compartment and Forchheimer's coefficient at 3e6 m^{-1}. Porosity has not been measured but due to the nature of the soil, it can be evaluated at 30% all over the test rig. The water saturation is estimated at 50%. The ground water level is at 1 m depth. Since the walls are at 1 m depth, gas cannot migrate in another compartment.

Methane injection was performed at 80 cm depth, close to the gas pipeline. Three configuration have been tested: 1 mm – 400 $mbar_g$, 1 mm – 2 bar_g and 1 mm – 4 bar_g (Table 6), but only the 1 mm – 2 bar_g will be presented here because it shows the most satisfactory results.

Table 6. Matrix of the configurations studied in the urban test rig of E.ON (TF3)

Test	Leak diameter (mm)	Inlet pressure (bar_g)	Inlet flow-rate (L(n)/min)
1 mm – 400 $mbar_g$	1	0.4	0.65
1 mm – 2 bar_g	1	2	2.4
1 mm – 4 bar_g	1	4	3.7

Probes were placed along all buried lines. No significant influence of them was observed. Gas seems to follow the contour of the pipelines. However, since only punctual measurements have been performed, numerical simulations must be used to reconstruct the global repartition of the gas in the test rig. These results will therefore be presented in the next part.

4 VALIDATION OF NUMERICAL CODES TO SIMULATE THE GAS MIGRATION IN SOIL

Three numerical codes aimed at the simulation of flow in porous media were used and compared to experimental data obtained on the GDF SUEZ and E.ON test rigs:

- TAGS: developed by GDF SUEZ with Osaka Gas and Tokyo Gas and then enhanced by CRIGEN for gas migration in soil studies;
- METIS: developed by Mines ParisTech, initially designed for the simulation of flow in aquifer porous media, but improved for the gas migration in soil;
- ANSYS CFX: commercial code developed by ANSYS, for the general simulation of fluid dynamics.

In this paper, only results from TAGS will be presented because work is still in progress with METIS and ANSYS CFX.

4.1 TAGS: a code specially designed for the gas migration in soil simulation

TAGS (Transient Advection of Gases in Soil) is a 3D code which was started to be developed in the 90's, by GDF SUEZ with Osaka Gas and Tokyo Gas, in order to answer gas migration in soils issues for low pressure leaks. Only equations related to this phenomenon are implemented in the tool.
The first version of TAGS enables the simulation of the gas propagation in soil in a porous media with Darcy's and Fick's equations. It calculates the pressure and the gas concentration using the finite elements method in a domain whose characteristics are defined by the user. Then, GDF SUEZ has continued to develop TAGS and Forchheimer's equation has been implemented in order to simulate high gas velocities. One of the main limit of TAGS is the fact that it considers density as constant when pressure increases. This can lead to important errors on the calculation of the pressure close to the injection point and as a consequence, on the gas flow.

TAGS allows to declare areas in soil with different physical properties. Indeed, after having declared an overall soil composition (porosity, permeability and diffusivity coefficient), the user can declare parallelepipeds whose characteristics are different, e.g. layers over the vertical axis, obstacles and holes at the limit of the domain. Initial conditions on pressure and concentration are also declared, and some areas can have particular conditions.

4.2 TAGS is validated for the simulation of gas migration in homogeneous soil

Data obtained in the GDF SUEZ test rig were used to validate TAGS in homogeneous situations. One of the strengths of this experimental campaign is that most parameters are known so that it is very easy to declare the input data of the simulation. The signals acquired by all probes for all configurations were compared, and it can be noticed that TAGS gives very satisfactory results. Some examples are showed in Figure 8 for case 5 mm – 400 mbar$_g$. The transient phase is well predicted, as for the steady state. TAGS only slightly over-estimates concentrations far from the injection, but it allows to be conservative. The constant pressure assumed by the model does not apparently modified results in the domain of interest. Some possible discrepancies may have been detected near the injection point if more sensors were implemented in this region.

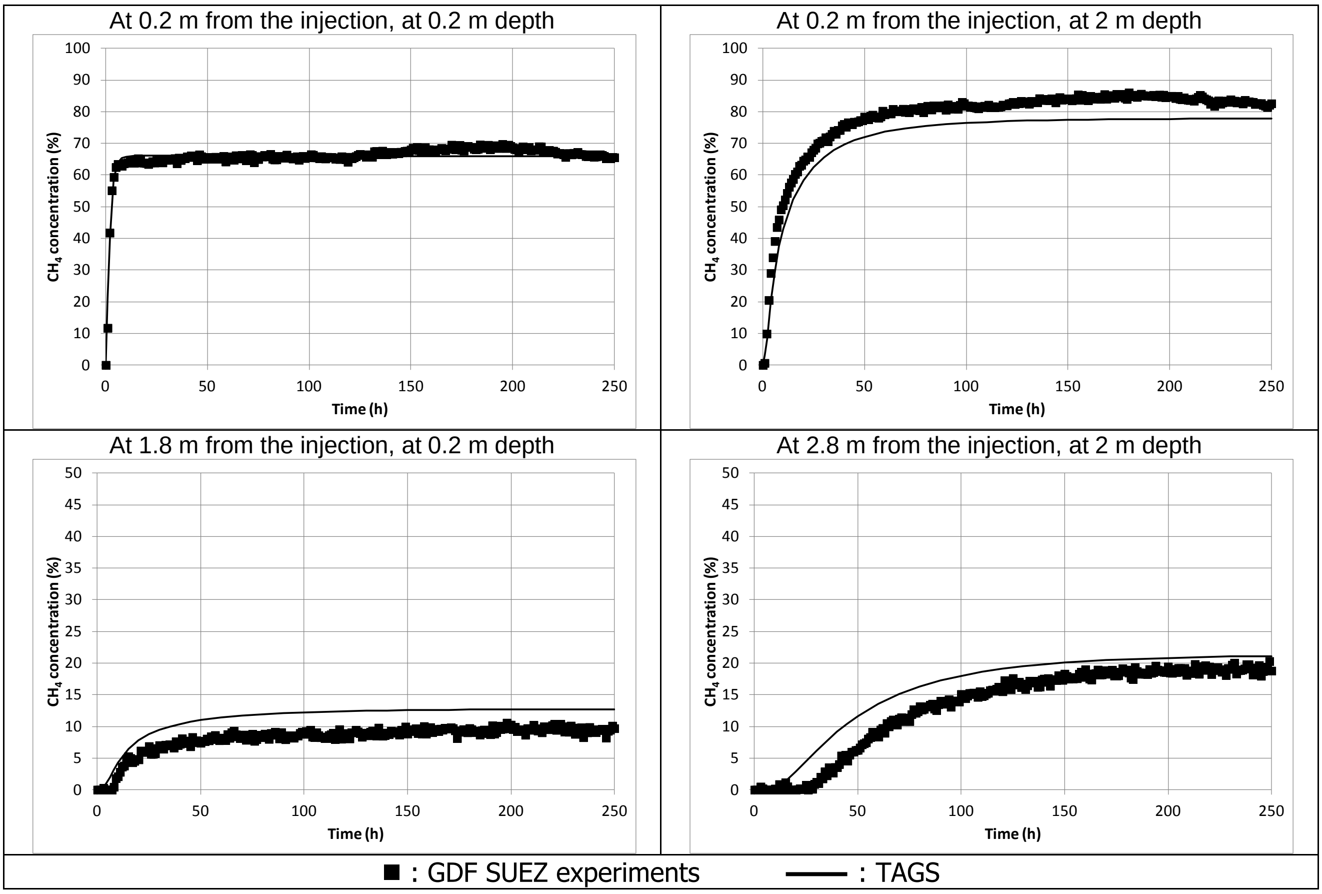
Thanks to these comparisons, TAGS is validated in homogeneous soils for leak flow-rates until 24 L(n)/min (1 mm – 15 bar$_g$ in the test field area).

4.3 TAGS properly simulates different top boundary conditions

The results obtained in rural conditions on TF2 (E.ON) were used to assess the ability of TAGS to take into account the influence of the nature of the top boundary condition. On the half part of TF2, a tarp was positioned so that no exchange between air and methane could occur. The tarp has therefore been considered as a wall. On the other half, it is grass and exchanges are possible.

On Figure 9, it can be noticed that TAGS manages to predict the effect of the tarp, representing, for example, an asphalt road. As observed experimentally, the influence of the top boundary condition is more important close to the surface.

The LFL distance at the ground surface was estimated with TAGS. The LFL distance is much higher on the tarp side than on the grass side. Indeed, for the case 1 mm – 4 bar$_g$ (Figure 10), LFL distance can reach 4.4 m on the tarp side, whereas it is only 2.3 m on the grass side.



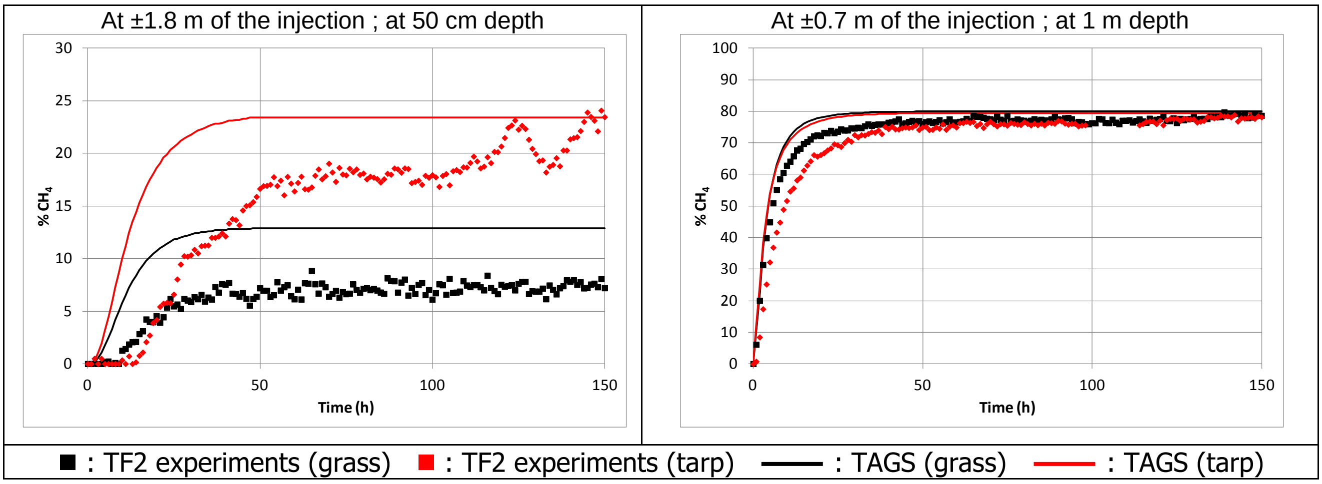
At 0.2 m from the injection, at 0.2 m depth

At 0.2 m from the injection, at 2 m depth

At 1.8 m from the injection, at 0.2 m depth

At 2.8 m from the injection, at 2 m depth

Figure 8. Evolution in time of the CH_4 concentration profiles obtained with TAGS for case 5 mm – 400 $mbar_g$ (GDF SUEZ test rig) at various position (R is the radial distance from the injection and Z is the depth)



At ±1.8 m of the injection ; at 50 cm depth

At ±0.7 m of the injection ; at 1 m depth

Figure 9. Influence of the top boundary condition on the case 1 mm – 220 $mbar_g$ on TF2: TAGS succeeds in simulating the phenomenon for two symmetrical points.

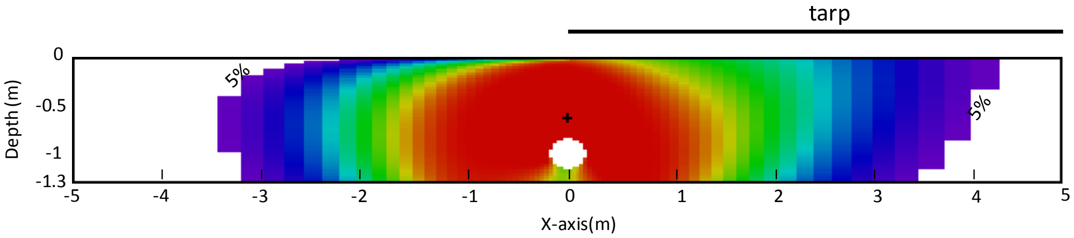


Figure 10. Simulation with TAGS of the case 1 mm – 4 bar_g on TF2 and study of the influence of the top boundary condition: LFL distances are higher on the tarp side

4.4 The use of simulation with TAGS allows to understand the influence of service lines on gas migration

From the experimental results of TF3, where a 110 mm diameter gas pipeline and three service lines have been set up, simulations with TAGS have been used to assess the influence of these obstacles. On Figure 11, it can be seen that pipeline and service lines do not have a strong influence on the gas propagation. Gas concentration seems lower under the pipeline. However, it is difficult to say if this is linked to physical or numerical reasons. Comparisons with other codes would help to understand this trend.
These small effects can be explained by the fact that the diameter of the service lines is small: 70 mm for the water waste line, 50 mm for the drinking water line and 20 mm for the phone line. After the setup of these lines, if compaction has been properly done to prevent the establishment of a preferential path, gas will only follow the contour of the gas line (according to the simulations).

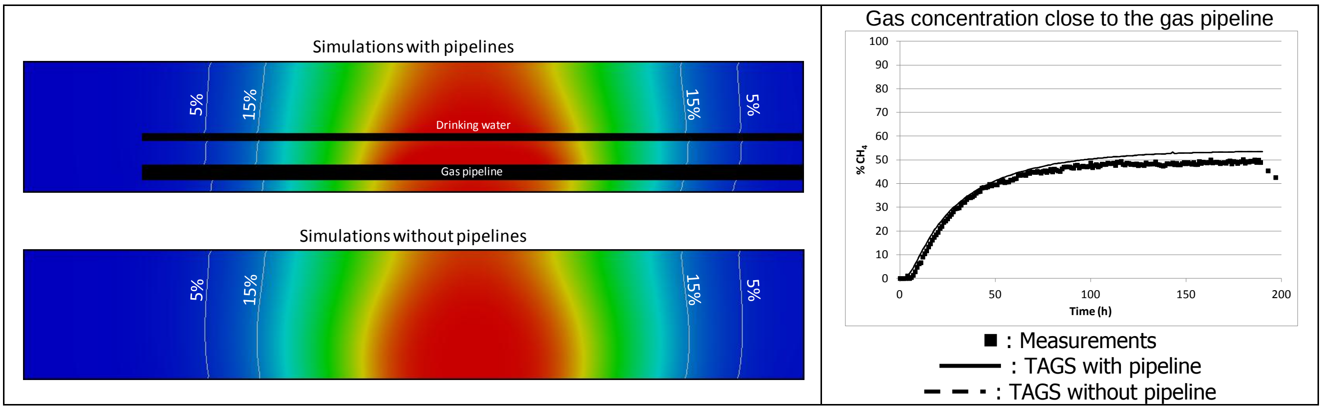


Figure 11. Visualization of the gas volume in the soil at t=8h along the gas pipeline axis for the case 1 mm - 2 bar$_g$ on TF3: very low differences with or without service lines.

5 CONCLUSION

The objective of this GERG project was to better understand the gas migration in soil phenomenon, to be able to assess time scales and typical distances. After the identification of representative leak configurations leading to gas migration in soil, experiments were performed in GDF SUEZ and E.ON. A large amount of data were acquired, in homogeneous and heterogeneous soils, with different boundary conditions and obstacles as pipelines. The main results of this work are:

- a steady state is always reached, usually after several days of injection;
- gas migrates further under an impermeable surface (ex: asphalt);
- for small service lines, further work are necessary to conclude, but when surrounding soil is well compacted, surrounding pipes seem to have little effect on gas migration;
- soil characteristics (permeability and Forchheimer's coefficient) can easily be assessed doing injections at various pressures, and then be declared as input data for simulations.

These data have been used to validate numerical codes. Three codes are being tested: TAGS, METIS and ANSYS CFX. Comparisons between experimental results and TAGS are very satisfactory. The work with the other codes is still in progress.

At the closing of this GERG project in May 2014, a device, easy to transport, is available to characterize gas migration in soil. The numerical code TAGS has been validated for pressures until 15 bar$_g$ and leak diameters of 1 and 5 mm. However, further work is necessary to investigate more deeply the influence of preferential paths on gas migration.