

Metánkibocsátás számszerűsítésének metodikája

Módszertan a számszerűsítés során

A környezetbe kijutó metán számszerűsítése során a következő lépések alapján jártunk el.

Első lépésben hálózati elemenként (assets) beazonosítottuk, hogy melyik szakirodalmi fajlagos értéket tudjuk felhasználni a mennyiség kalkulációjához. A fajlagos érték és az adott hálózati elem jellemzőinek (hossz, db, anyag, időtényező) szorzatai alapján kalkuláltuk az eszközök kiáramló földgáz mennyiségét Nm³-ben.

Ezután a kiáramló földgáz mennyiségét korrigáltuk annak metántartalmával, amit a hazai földgázszállítási rendszerüzemeltető 95,822%-ban határoz meg. (forrás: <https://fqsz.hu/a-foldgazrol/mi-a-foldgaz>)

Harmadik lépésben a meghatározott Nm³ metán mennyiséget átváltottuk tonnába. Ehhez 0,714 kg/m³ sűrűségi értéket használtunk.

Utolsó lépésben a kapott t metán értéket átváltottuk tCO₂ egyenértékekre. Az átváltási tényező 25 tCO₂/tCH₄ az Eurostat adatai szerint. (forrás: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent)

Permeáció

A permeáció az a folyamat, amely során a gáz vagy folyadék molekulái nyomáskülönbség hatására áthatolnak a szilárd anyagon. A permeáció a PE anyagú vezetékek esetén releváns, a metán molekulák átdiffundálnak a PE anyagú vezeték falán annak ellenére, hogy meghibásodás, illetve tömörtelenségi probléma lépne fel az adott szakaszon

A Kiwa kutató és tanúsító cég méréseken alapuló (a DÉGÁZ elosztóterületén is folytak mérések, az akkori vezetés közreműködésével) tanulmány keretében kiszámította a PL – permeációs veszteségeket. A riportban szereplő értékeket átszámítottuk a saját üzemi nyomásaink alapján, majd a szakági nyilvántartásból lekértük a permeáció során releváns vezetékek hosszát nyomás szerinti bontásban. Ezen adatok felhasználásával határoztuk meg a permeáció mértékét.

p [bar]	PL [m ³ /km/év]
0,03	0,0033
0,05	0,00495
0,1	0,011
0,3	0,033
0,5	0,055
1	0,11
1,5	0,165
1,7	0,187
2	0,22
2,5	0,275
3	0,33
4	0,44
4,5	0,495
5	0,55
6	0,66
7	0,77
8	0,88
10	1,1
35	3,85
40	4,4

*Felhasznált anyag: Scholten, Frans L. ; Wolters, Mannes. / **Methane permeation through advanced high-pressure plastics and composite pipes**. Proceedings Plastic Pipes Symposium XIV. editor / Z. Davidovski ; P. Belloir ; J. Fumire. Budapest, Hungary, 2008.*

Szivárgásokból eredő metánkibocsátás

Ütemezett LDAR program keretében végzett szivárgáskeresési tevékenységek, illetve külső bejelentések során behatárolt gázszivárgási eseményekből eredő metánkibocsátás. A gázszivárgások kezdeti időpontjának 2024.01.01-ét, a szivárgás végének a hiba végleges elhárításának időpontját határoztuk meg.

Az európai GERG (The European Gas Research Group) projekt keretében a Kiwa kutató és tanúsító cég vákuumos módszer alkalmazásával méréssorozatot végzett. A tesztek során anyag és nyomás alapján kibocsátási tényezőket mértek ki. A riportban szereplő értékeket átszámítottuk a saját üzemi nyomásaink alapján, majd ezeket felhasználva lekérdeztük a műszaki adatbázisunkból a meghibásodásokat, azokat nyomás szerint csoportosítottuk és hozzárendeltük a kibocsátási tényezőket.

p [bar]	q [l/h]
0,03	205
0,045	145,5
0,1	231
1	31
2	40
2,5	44,5
3	49
4	713
4,5	696,5
6	647
8	581

Felhasznált anyag: Kiwa N.V.; GERG; C.J.A. (Kees) Pulles; E.H. (Erik) van den Brink / *Quantifying leakage from underground pipelines. Apeldoorn, The Netherlands, 2020*

Lefúvatás és fáklyázás

Lefúvatási és fáklyázási esemény során saját képletet alkalmazunk a kiáramló gáz mennyiségének meghatározására. Figyelembe vesszük a vezeték geometriáját és a benne lévő földgáz nyomásának mértékét.

$$Q = A \cdot l \cdot (p_0 + p) = \dots [m^3]$$

- A – kiáramló keresztmetszet,
- l – lefúvatott vezeték hossza,
- p_0 – környezeti nyomás,
- p – vezetékben lévő túlnyomás

Harmadik feles rongálások

Harmadik feles rongálási esemény során az áramlástani módszertanokat vesszük figyelembe. A témában publikált anyagok felhasználása alapján az alábbi képletet alkalmazzuk a kiáramló gáz mennyiségének meghatározására.

$$Q_{p < 0,88 \text{ bar}} = A [m^2] t [s] \cdot \sqrt{8,255183 \left[\frac{J}{kgK} \right] T [K] \cdot \left\{ 1 - \left(\frac{P_0}{P_0 + p} \right)^{0,231} \right\}} = \dots [m^3]$$

- A – kiáramló keresztmetszet,
- t – kiáramlás ideje,
- T – gáz hőmérséklete,

- p_0 – környezeti nyomás,
- p – vezeték nyomásfokozata

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Nyomásszabályzó állomások

A Marcogas SURVEY METHANE EMISSIONS FOR GAS DISTRIBUTION IN EUROPE tanulmányban szereplő átlagos kibocsátási tényezőt használtuk fel a számszerűsítésre.

Material	Average emission factor
City Gates	198 kg CH ₄ / City Gate

Társaságaink műszaki adatbázisából nyomásszabályzó állomások listája lekérdezésre került.

Felhasznált anyag: MARCOGAZ - THE TECHNICAL ASSOCIATION OF THE EUROPEAN GAS INDUSTRY, SURVEY METHANE EMISSIONS FOR GAS DISTRIBUTION IN EUROPE, Update 2017, FEBRUARY 8, 2018

METHANE PERMEATION THROUGH ADVANCED HIGH-PRESSURE PLASTICS AND COMPOSITE PIPES

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ABSTRACT

There is a clear market wish to use plastic and composite pipes for natural gas pipelines at higher pressures than the traditional limit of 10 bars for PE100 pipes. Candidates are Polyamide 12, plasticized PA6.12, Polyamide 11, other long-chain Polyamide pipes and PE-based composite pipes (Multilayer M pipes). However, at higher pressures permeation of natural gas through the wall of plastic or composite pipes increases, depending on materials composition and SDR. An international testing programme was started to measure the permeation rate and permeability coefficient of 14 different 110mm plastic and composite pipes. Sponsors are pipe and resin manufacturers and GERG (European Gas Research Group). Included in the investigation were 5 different brands of Polyamide pipe, a pipe produced from a PE100 resin containing 10% of a special anti-permeation additive and a RTP Light pipe. Two PE100 pipes were measured for reference. Using the permeation curves, the permeability coefficient PC (in ml.mm/m²/bara/day), diffusion coefficient D (in cm²/sec.) and solubility coefficient S (in kbara⁻¹) for methane have been calculated for all measured pipes. The PA pipes show only a few percent of the permeability coefficient of PE100 pipe. The PE100 pipe containing 10 % of a special anti-permeation additive possesses a 5.2 times lower permeability coefficient than regular PE100 pipe. Therefore, this modified PE100 pipe shows a permeation rate in between the values for PE100 and PA pipes.

INTRODUCTION

Any plastic material will show some permeation of methane or other gases, although the permeability coefficient (permeation rate under standard conditions) can be very different for different polymers. Because the pipe systems investigated in this project are intended for natural gas pressures higher than 10 bars, the permeation rate is more important than for pipes only used at lower pressures.

There could be three reasons to assess permeation losses through the wall of plastic pipes in gas distribution systems:

1. The economic value of lost natural gas
2. Contribution to global warming and climate change caused by these permeation losses.
3. Safety issues, because permeated gases may accumulate in unwanted and unexpected locations.

It is clear that reasons 1 and 2 are not important enough. Natural gas leakages at pipeline connections and joints are much more important than permeation losses, both from an economical and from a “climate change” point of view.

This leaves safety as most important reason to investigate permeation losses. Permeated gas may flow several meters away from a pipeline and accumulate elsewhere. In rare occasions this may lead to flammable or explosive mixtures with air at unexpected locations. Accumulation may occur under the following conditions:

- in impermeable soil
- under impermeable pavements
- near impermeable foundations of buildings
- inside protective jacket pipes.

Still, permeation does not imply any loss of mechanical integrity of the pipeline.

Plastic pipes intended for pressures above 10 bars can be made of different types of PA resins, like PA12, PA11, plasticized PA6.12 or other long-chain PA. RTP (Reinforced Thermoplastic Pipes, containing aramid or other fibres ^[1]) and multilayer PE100 pipe strengthened by highly oriented PE100 foil ^[2] are also possible. Most of these pipe materials have been investigated in this work.

The goal of the work is to determine the permeability coefficient of the different pipe materials. The measurements have been performed on whole pipe segments and not on foils.

EXPERIMENTAL METHODS

Materials

All investigated pipes had a nominal diameter of 110 mm, except pipe 11 (Table 1).

Investigated were 3 types of PA12 pipe, all 110mm and SDR11 (pipes 1, 2 and 3). A fourth PA material, a plasticized PA6.12 grade was also investigated (pipe 7). Pipe 6 is still under test.

Table 1. Investigated pipe materials. All pipes 110 mm, except pipe 11 (125 mm). Most are SDR11, except 4, 5 and 11.

Pipe nr.	Pipe	Resin manufacturer	Grade name	SDR
1	PA12	Evonik Degussa	Vestamid [®] LX9030	11
2	PA12	EMS-GRIVORY	Grilamid [®] FE 8566	11
3	PA12	Ube	Ubesta [®] 3035 UF	11
4	PE100 + 10 % UB39	DuPont	Pipelon [®] UB39	15.8
5	PE100			15.8
6	Long chain PA	DuPont	Pipelon [®] HT	11
7	plasticized PA6.12	DuPont	Pipelon [®] 401	11
11	PE100 multilayer	Pipelife	RTP “Light”	8.9
15	PE100	-	-	11

Three pipes were investigated produced by Pipelife (Netherlands), pipes 4, 5 and 15. Pipe 5 is a modified PE100 pipe with an usual SDR of 15.8 (7 mm wall thickness). The composition was this pipe is PE100 resin containing 10% of a special anti-permeation additive. Pipe 4 is a normal PE100 pipe with the same wall thickness and SDR, to allow comparison with pipe 4 at the same pipe dimensions. Pipe 15 is a SDR11 110mm PE100 pipe, used as reference in this publication.

Finally, a fourth pipe from Pipelife in Netherlands was investigated, a Reinforced Thermoplastic Pipe (pipe 11). This pipe was denoted “RTP Light”, with a diameter of 125 mm and wall thickness of 14 mm.

Methods

The typical shape of a permeation curve is (Figure 2 and Figure 3):

- At first no there is no permeation, followed by:
- Slow increase of the permeation rate (the slope) and finally:
- Steady state permeation with constant slope.

The permeation rate is linearly related to the slope of the curve in the final, linear part. From this slope the permeability coefficient PC can be calculated, by taking into account the wall thickness, pipe diameter, volume of the jacket pipe used for accumulation of permeated gas and the pressure difference (in bar(a), with respect to vacuum). The formula is given in equation (1):

$$PC = Q \cdot e / (A \cdot \Delta P) \quad (1)$$

In which:

PC is in ml.mm/m²/day/bara

Q is in ml/day

e = wall thickness in mm

A = surface area of the pipe in m²

ΔP = pressure difference for methane in bara (with respect to vacuum)

Permeation and the Median Pipe Diameter

The pipe diameter that is used for the calculations needs consideration. This is illustrated in Figure 1.

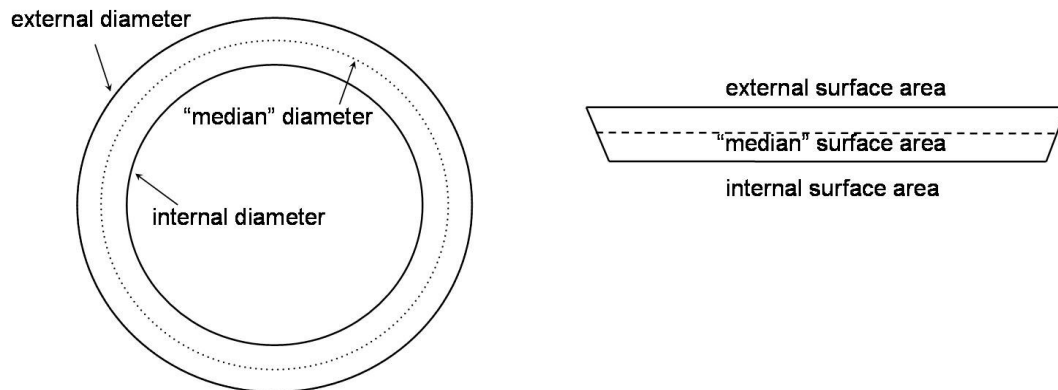


Figure 1. The external diameter D_e , the internal diameter D_i and the “median” pipe diameter D_m . At right: “flattened pipe”.

The median pipe diameter (D_m) is the diameter halfway between external diameter (D_e) and internal diameter (D_i). In formula:

$$D_m = (D_e + D_i)/2 \quad (2)$$

The right-hand part of Figure 1 illustrates that the median surface area A (in m^2) through which permeation takes place is the correct choice. The external surface area is too large and the internal surface area is too small. The median surface area A is defined in equation (3):

$$A = \pi \cdot D_m \cdot L \quad (3)$$

In which:

L = the length of the jacket pipe (m).

D_m is in meters as well.

Further:

$$D_m = D_e \cdot (SDR-1) / SDR \quad (4)$$

This leads to the general permeation equation for pipes:

$$PC = 1000 \cdot Q / (\pi \cdot (SDR-1) \cdot L \cdot \Delta P) \quad (5)$$

It is emphasised again that L is in meters.

This formula means that the permeability coefficient is not directly dependent on the pipe diameter and wall thickness separately, but only on the ratio between both, the SDR, via the factor $(SDR-1)$. At constant SDR, a larger pipe diameter is exactly compensated by the increase in wall thickness.

Diffusion coefficient and solubility

There is more information to be derived from the permeation curves. When the straight line in the final linear part of the curve is extrapolated back to the x- axis, a breakthrough time (BT) is found (in days). From BT the diffusion coefficient D can be calculated ^[3, 5] by equation (6):

$$BT = (e)^2 / (6 \cdot D) \quad (6)$$

in which D is the diffusion coefficient in mm^2/day , which value is converted to cm^2/sec .

Finally, the solubility (S) of the methane gas in the polymer materials can be calculated by equation (7) ^[3, 4]:

$$PC = D \cdot S \quad (7)$$

The unit of S is $bara^{-1}$ or $kbara^{-1}$. This means that the solubility of methane in the polymer is linearly dependent on the methane partial pressure (in bara). This is in agreement with Henry's Law ^[6].

Comparison with Other Laboratories

One reference PE100 pipe (pipe 15, see Table 1) was used for an inter-laboratory comparison of permeation results. The participating labs are mentioned in Table 2.

Table 2. The 3 labs that have performed permeation measurement on the same PE100 pipe nr. 15.

Lab code	Laboratory	Country
A	Gaz de France/Degaz	Hungary
B	DBI	Leipzig, Germany
C	Kiwa Gas Technology	Apeldoorn, Netherland

RESULTS

All measurements described in the Results section have been performed by lab C (Table 2). Additional data measured by other labs are presented under Discussion in Table 5.

The results of permeation experiments on 110mm SDR11 PA pipes are presented in Figure 2. The results of PE100 reference pipe 15 are included.

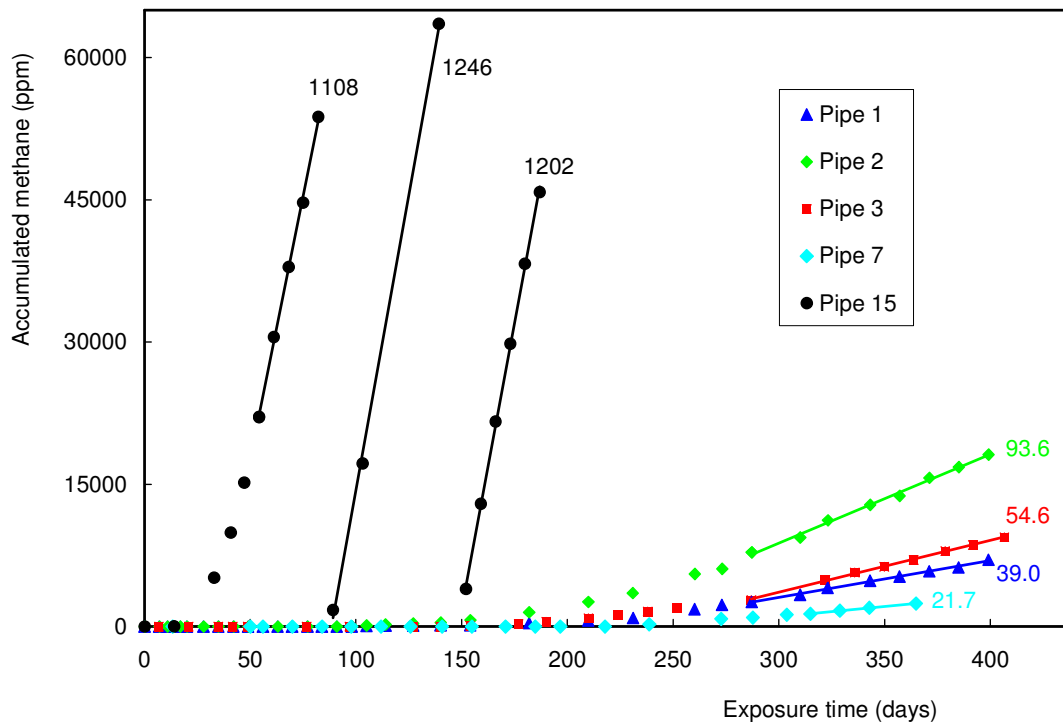


Figure 2. Accumulation of methane in a jacket pipe after permeation through the wall of 4 PA pipes and a PE100 pipe. All pipes SDR11 and diameter 110mm. Please note PA7 was measured at 16 bar(g), whilst the other pipes were all measured at 10 bar(g). The numbers near the straight lines are the permeation rates in ppm/day.

The results of the measurements are summarized in Table 3.

Table 3. Permeability coefficient (PC), Diffusion coefficient (D) and Solubility of methane (S) of 4 PA pipes, 2 PE100 pipes and a pipe containing a PA/PE100 mixture.

Pipe nr.	Pipe	PC (ml.mm/m ² /bara/day)	D (cm ² /sec)	S (kbara ⁻¹)
1	PA12	0.92	8.95 10 ⁻⁹	11.8
2	PA12	2.20	9.62 10 ⁻⁹	26.4
3	PA12	1.28	8.26 10 ⁻⁹	17.9
4	PE100 + UB39	7.0	1.8 10 ⁻⁹	46.0
5	PE100	36.6	5.57 10 ⁻⁸	76.0
6	Long chain PA	Under investigation		
7	Plasticized PA6.12	0.40 *	7.65 10 ⁻⁹ *	6.0 *
11	RTP	Under investigation		
15	PE100	34.1	6.42 10 ⁻⁸	61.5

* preliminary value, based on 4 data points in the linear range in Figure 2
PE100 pipe 5: 110mm PE100 pipe with a wall thickness of 7mm (SDR 15.8)

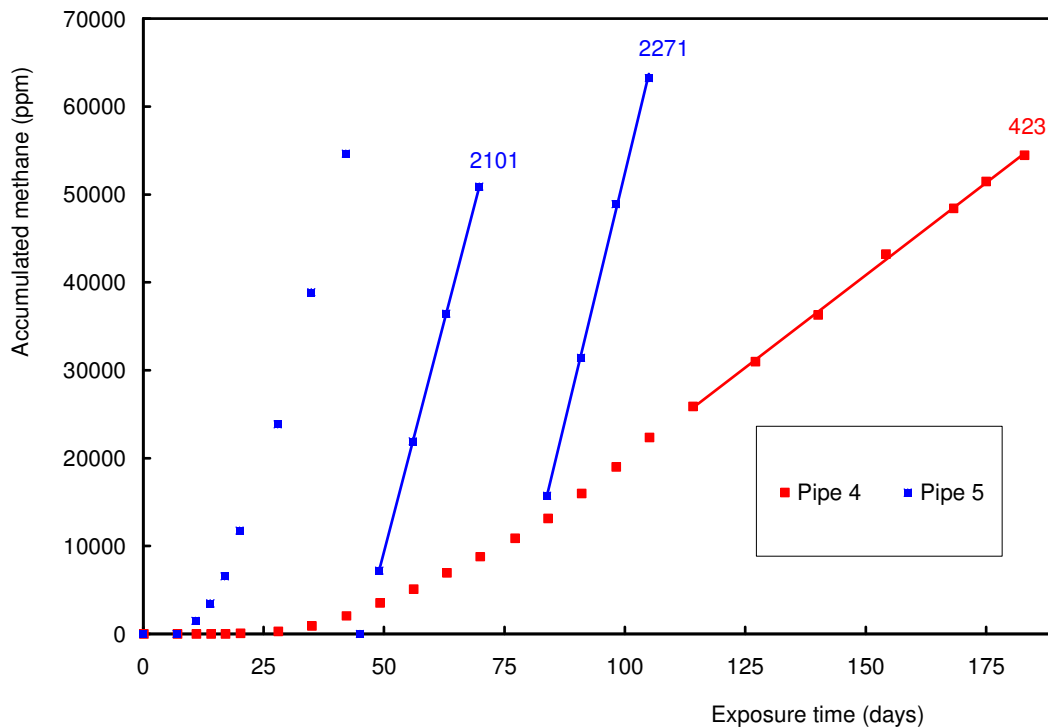


Figure 3. Accumulation data of a PE100 pipe with special anti-permeation additive and a PE100 reference pipe.

DISCUSSION

The diffusion coefficient of PE (density 964 kg/m³) was reported earlier by Stannett as $5.7 \cdot 10^{-8}$ cm²/sec ^[7]. The values for pipe 5 and 15, PE100 materials with a similar density, compare favourably with this value.

Pipe 1 and pipe 3 are both produced from PA12 resins and therefore show similar results. Pipe 2 is also produced from PA12 resin, but the value is higher. The reason is not known. Initial results obtained at 16 bars methane pressure (see Future work) confirm these differences.

The permeability coefficients of the 4 PA pipes are much lower than the permeability coefficient of PE100 pipe. Even when PA pipes will be used at higher pressures than PE100 pipes, the permeation rate will be much less. From a permeation point of view, this makes PA an attractive plastic pipe material for gas transport.

Table 4 shows the factor by which the permeability coefficient is reduced with respect to PE100 pipe. The average of the values of the 2 PE100 pipes in Table 3 (5 and 15) was taken as reference, except for pipe 4.

Table 4. Permeability coefficient of PA pipes with respect to the permeability coefficient of PE100 pipes.

Pipe	Reduction in Permeability coefficient in comparison to PE100 pipe	Remark
1	39	
2	16	
3	28	
4	5.2	Compared to pipe 5
7	87	

It appears that addition of an anti-permeation component to PE100 pipe is an interesting option. Adding 10% of Pipelon[®] UB39 reduces the permeability coefficient PC of this modified PE100 pipe by a factor of 5.2.

It appears that pipe 4, with 10% of an anti-permeation component added to PE100 resin, takes an intermediate position between PE100 pipe on the one hand and PA12 and plasticized PA6.12 pipes on the other hand.

Measurements by Other Laboratories

Two other labs (Table 2) have also made permeation measurements on the PE100 reference pipe (nr. 15). The results are presented in Table 5. The column PL is explained in a next section.

The values obtained by the 3 labs compare relatively well.

Table 5. Permeability coefficient (PC), Diffusion coefficient (D) and Solubility of methane (S) of reference pipe 15, a 110 mm SDR11 PE100 pipe, measured by 3 laboratories. One additional value for pipe 5 and a measurement at 8 °C on pipe 15 were added for comparison.

Pipe	Lab	Temperature (°C)	PC (ml.mm/m ² /bara/day)	D (cm ² /sec)	S (kbara ⁻¹)	PL (10 barg) (m ³ /km/year)
15	A	21	26.2	5.22 10 ⁻⁸	58	3.3
15	B	21	27.1	-	-	3.4
15	B	21	36.8	5.37 10 ⁻⁸	79	4.6
15	C	21	34.1	6.42 10 ⁻⁸	61	4.3
5	C	21	36.6	5.57 10 ⁻⁸	76	4.6
15	A	8	8.7	2.64 10 ⁻⁸	38	1.1

The Influence of Temperature

Gas pipelines are installed underground. Typical soil temperatures often vary between 8 and 14 °C. Therefore it is important to know the permeability coefficient of the investigated pipes in this temperature range. For one pipe, the PE100 SDR11 reference pipe nr. 15, a measurement was performed at 8 °C by lab A. The value is given in Table 5 as well.

It appears that the influence of temperature on the permeability coefficient is relatively large. At 8 °C the permeation rate of PE100 pipe is about 3 times as low as at 21 °C.

Practical Permeation Losses

The last column in Table 5 illustrates what the permeation loss under practical circumstances of the investigated pipes is. All calculations were made for 10 bar(g) methane pressure and SDR11. This Permeation Loss (PL) is given in cubic meters of methane per kilometre pipeline length per year. Equation (5), the general permeation equation for pipes was used, because PL is actually Q / L in that equation, at a known permeability coefficient.

It is emphasized that these values are only valid for PE100 pipes. Based on other permeation results at the lab of the authors, it may be expected that PE80 MDPE pipes will have a PL about 1.5 times as high.

It is possible to calculate the permeation rate for pipes with another SDR value, also by using equation (5). The conversion to a pipe with another SDR value is based on the factor (SDR-1) in that equation.

CONCLUSIONS

- The permeability coefficients measured by 3 laboratories on a PE100 reference pipe are similar. There also is a good correlation between the diffusion coefficient for PE100 and a literature value.
- Polyamide pipes (PA12 and plasticized PA6.12) possess a permeability coefficient which is 16 to 87 times lower than the permeability coefficient of

PE100 pipes. Hence, from a permeation point of view these long-chain PA pipe materials are attractive for natural gas transport and/or distribution.

- The investigated pipe which consists of a mixture of 10% of a special PA-based anti-permeation additive with PE100 resin shows a reduction in permeability coefficient by a factor of 5.2.

FUTURE WORK

The project is continued with:

- Completing permeation measurements on the PA12 pipes, the plasticized PA6.12 pipe and another long-chain PA pipe at 16 bars methane pressure.
- Completing permeation measurements on the RTP Light pipe.
- Measuring permeation of hydrogen gas at 10 bars of the 3 PA12 pipes.

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SURVEY METHANE EMISSIONS FOR GAS DISTRIBUTION IN EUROPE

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Table of Contents

1.	SUMMARY	3
2.	INTRODUCTION	5
3.	LIST OF DEFINITIONS	6
3.1.	Emissions: sources of Methane	6
3.2.	Gas system.....	6
3.3.	Emission measurement methodology.....	7
3.4.	Geographical boundaries	8
4.	RESULTS	9
4.1.	Data collection.....	9
4.2.	Description of the method	9
4.3.	Evaluation of the quality of the data set	9
4.4.	Emission factors distribution networks	11
4.4.1.	Correlation.....	11
4.4.2.	Analysis of the emission factors by pipeline materials.....	12
4.4.3.	Emission factors for service lines and City Gate stations	17
4.5.	Activity factors EU28 distribution networks.....	18
4.6.	Methane Emissions for EU28 distribution networks.....	20
4.6.1.	Emissions from distribution pipelines.	20
4.6.2.	Emissions from service lines and City Gate stations.....	23
4.6.3.	EU28 emission totals from distribution grids	23
5.	CONCLUSIONS	26
6.	BIBLIOGRAPHY	28
7.	APPENDIX.....	29
7.1.	APPENDIX I: MARCOGAZ forms Methane emission	29
7.2.	APPENDIX II: MARCOGAZ members	30
7.1.	APPENDIX III: EU28	31

Figures

Figure 1: Regression analysis CH ₄ emissions vs. grey cast iron pipelines length	12
Figure 2: Regression analysis ductile cast iron CH ₄ emission vs. pipeline length	13
Figure 3: Regression analysis, steel CH ₄ emission vs. pipeline length	14
Figure 4: Regression analysis polyethylene (PE) CH ₄ emission vs. pipeline length	15
Figure 5: Regression analysis pipeline length PVC versus CH ₄ emission.	16
Figure 6: Regression analysis pipeline length 'not specified' vs. CH ₄ emission.....	17
Figure 7: Average emission factors (in kg CH ₄ / km) distribution pipelines per type of material.	21
Figure 8: Distribution pipeline length (in km) per type of material	22
Figure 9: Distribution pipelines CH ₄ emissions (in tons) EU28 per type of material.	22
Figure 10: Distribution of CH ₄ emissions depending on Activity factors in EU28	25
Figure 11: EU28	31

Tables

Table 1: Datasets distribution	10
Table 2: Emission factors for cast iron	13
Table 3: Emission factors for steel.....	15
Table 4: Emission factors for Polyethylene	15
Table 5: Emission factors for PVC.....	16
Table 6: Emission factors for pipeline in the category not specified.....	17
Table 7: Emission factors for Service Lines and City Gate stations.	18
Table 8: Activity factors for EU28 DSOs	19
Table 9: References DSO emission factors EU28.....	20
Table 10: EU28 Methane emissions from DSO pipelines (average)	20
Table 11: EU28 Methane emissions from DSO pipelines (95%UCL).....	21
Table 12: Average emission factors for service lines and City Gate stations.	23
Table 13: Average emission factors for service lines and City Gate stations.	23
Table 14: EU28 CH ₄ emission DSO grids (Average)	24
Table 15: EU28 CH ₄ emission DSO grids (95% UCL).....	24

1. SUMMARY

The impact of Greenhouse Gases on climate change has been recognized for some time which has led to measures aimed to reduce global warming. Methane (CH₄) which is the major component of Natural Gas and identified as a Greenhouse Gas (GHG).

As Natural Gas is a major source of energy for the society, it is the role of the gas network operators to deliver continuous and safe service whilst managing responsibly the impacts on the environment.

MARCOGAZ, the Technical Association of the European Gas Industry, considers that it is important for the Gas Industry to understand and quantify its emissions of Natural Gas. It is also important to be transparent about the methodology used to calculate the emissions and to demonstrate that best practices are used across the European Gas Industry.

This study is an update of the 2014 study (based on a 2009-2013 dataset). A new set of data from 2015, more relevant and more accurate, has been added to the available dataset of 2013 to study the contribution of the Methane emissions from the natural gas distribution network in the EU28. Further emission factors for the different type of materials are calculated in their total contribution to the greenhouse gasses of the EU28.

The total amount of Methane emitted in Europe via the Natural Gas distribution network was estimated by MARCOGAZ reusing and enhancing the statistical methods used in 2014 report. The representative dataset of 2013-2015 is representing and 43% of the European distribution network pipeline length. It is reasonably assessed as globally representative of the European distribution Network, although further improvements can be made in the data collection methods

Nevertheless, MARCOGAZ continues through its Working Group Methane Emissions to investigate better methods to measure and estimate Methane emissions in the gas supply chain.

Based on that study:

- ✓ The total estimated amount of Methane emissions from distribution grid is in the range of **339 – 553 kT Methane**.
- ✓ On that base the methane emissions from distribution grids are estimated to be in the range of **9.492 and 1.549 kT CO₂eq**¹
- ✓ Considering these figures, the total distribution network losses ⁽²⁾⁽³⁾ are calculated to be in the range of **0,1% to 0,2%**. In this figure the losses of the grid, but also the losses from service lines and the City Gate stations are included.
- ✓ The maximal yearly Methane emission rate on the EU28 distribution network is:

Pipeline material	Maximal emission rate	Share of the EU28 grid
Cast iron	1.388 kg CH ₄ / km	2,5 %
Steel	198 kg CH ₄ / km	39 %
Polyethylene	61 kg CH ₄ / km	51 %
P.V.C.	34 kg CH ₄ / km	5 %
Service lines	1,52 kg CH ₄ / customer	

- ✓ The total amount of GHG emissions caused by the Methane emissions from Natural Gas distribution grids is estimated to be **between 0,2% - 0,3%** of the total of anthropogenic⁴ GHG emission in Europe (EU28)⁵.

¹ GWP: Global Warming Potential; GWP100 of CH₄ (= 28) is used according to the Fifth Assessment Report (AR5) - IPCC.

² Compared to the total of natural gas sales in Europe - EU28 inland gas sales: EUROGAS Statistical report 2015.

³ Please note that such a comparison is valid only at a European level, as, at a country level, not all the gas contained in the network at a moment in time will be sold in that particular country

⁴ Anthropogenic emissions: emissions originating in human activity

⁵ Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015, EEA report No 23/2016, page 76
Page 4 of 31

2. INTRODUCTION

In the past five years an increasing number of reports from reputable institutions have highlighted the environmental impact of global warming and the accelerating effect that the continued release of Greenhouse Gases to atmosphere is having on this phenomenon.

This changing attitude of governments, regulatory bodies and the general public has resulted in increasing attention being paid to the Methane releases from the gas networks across Europe.

Significant literature has been published which proposes various methods of estimation. This is further complicated by the differences in the different Countries.

MARCOGAZ developed and published (2005) a methodology using all existing knowledge available within the group of European gas infrastructure operators.

As Countries have differences in their operating regimes, the common methodology would allow a common approach to the estimation of Methane emissions available.

In 2007 a first assessment was made to derive a range for emission factors for gas transmission and distribution. In 2014 this assessment was repeated to look at developments of the emission factor, but also to give an estimate of the total Methane emissions from Natural Gas Industry.

The 2014 Survey on Methane emission for gas transmission and distribution (Ref. WG-ME-14-26_D096), has explored several statistical scenarios, and defined the best option to give an estimate of the total Methane emissions from natural gas industry, based on 2009 to 2013 data.

The following study updates the 2014 survey, using a significant set of updated data from 2013 – 2015.

Only Methane emissions from gas distribution networks are considered here.

3. LIST OF DEFINITIONS

In order to obtain comparable objective emission calculations or estimations, the use of identical definitions is necessary. For this reason, a number of definitions are given hereunder.

3.1. Emissions: sources of Methane

- ✓ *Fugitive emissions*: All residual leaks from flanges, pipe equipment's, valves, joints, seals and seal gas systems etc. that are more or less continuous sources.
- ✓ *Pneumatic emissions*: All emissions caused by gas operating valves, continuous as well as intermittent emissions.
- ✓ *Vented emissions*:
 - o *Maintenance vents*: Methane emissions from or planned operating conditions where significant volumes of Natural Gas can be released to atmosphere from the gas network for maintenance purposes.
 - o *Incident vents*: Methane emissions from unplanned events. This will normally be from failures of the system due to third party activity and external factors normally outside of the control of the gas company.
 - o *Operation vents*: i.e. starting and stopping of the compressors.
- ✓ *Incomplete combustion emissions*: Unburned Methane in the exhaust gases from gas turbines, gas engines and combustion facilities and flares.

3.2. Gas system

- ✓ *Transmission system*: High-pressure gas transport over long distance including pipelines, compressor stations, metering and regulating stations and a variety of above-ground facilities to support the overall system. Underground gas storage and LNG are excluded. Transport from production companies to the distribution companies and to the industries. Operating pressure is normally equal or greater than 16 bar.
- ✓ *Distribution system*: Medium to low pressure transport including distribution pipelines, service lines and a variety of above-ground facilities to support the overall system. Local transport from transmission system to customer meters. Pressure normally ranges less than 5 bar. But new polyethylene systems up to 10 bar are now developed in some EU countries. Medium pressure: 0,200 – 5 bar. Low pressure: less than 200 mbar.

Note: The part of the system under 16 bar and above 5 bar can be considered in transmission or distribution, depending on the system boundaries adopted by each company and/or on the techniques used (steel, polyethylene...).

3.3. Emission measurement methodology

To obtain these results, different leak measurement techniques are used in Europe to determine the total leak rate of pipelines.

Each technique to measure gas leaks is a combination of a sampling method and a sensor technique which are used for the leak rate computation.

'Sampling methods' are:

- 1) **Leak flow capturing:** capturing the leaking gas as completely as possible, by encapsulating the leaking components.
- 2) **Full suction method:** capturing as much of the leakage by (partial) enclosing the leaking components, diluting the leakage using excess suction
- 3) **Partial suction method:** capturing the leakage partially, diluting the leakage using excess flow suction
- 4) **Direct method, optical:** no explicit sampling, but using optical path concentration sensors
- 5) **Direct method, pressure decay**

Methods 1, 2 and 3 can also be modified by adding a tracer gas (e.g. He or SF₆) to the leaking flow. This can improve sensitivity and/or accuracy using suitable tracing gas/sensor combinations.

'Sensor techniques' are based upon a variety of sensors that measure a specific property of a gas mixture. The most common techniques are: 'flame ionization', 'thermal conductivity measurement', 'catalytic oxidation' (calorific value measurement) and 'infrared absorption' (spectral methods)

For the optical direct method, infrared absorption methods are available. There are active methods using infrared light beams (leds and laser, lidar) or passive methods using thermal or spectral imaging cameras.

The pressure decay method is special in the sense that it is not based on measuring any gas mixture composition, but only pressure (and sometime temperature) as function of time.

Measurement of underground leaks come with additional challenges caused by the soil.

Each measurement technique has its own pros and cons in regard of time, effort and reliability however there is no comparative research available.

(Source: Kiwa Technology, the Netherlands)

3.4. Geographical boundaries

The estimations for Methane in this report for transmissions companies in Europe are based on the MARCOGAZ Members representing the Countries shown in paragraph 7.2 (APPENDIX II: MARCOGAZ members).

4. RESULTS

4.1. Data collection

MARCOGAZ started a survey among its Members in September 2016 with the question to fill in the form of the MARCOGAZ method (see 7.1 - APPENDIX I: MARCOGAZ forms Methane emission). With the forms returned and the data already available from the year 2013, the survey was performed.

The dataset covers the equivalent of 46% in length of the European (EU28) distribution network.

4.2. Description of the method

The evaluation of total emissions is based on the following equation:

$$\text{Methane emission} = \sum (AF \times EF)$$

Where:

AF = activity factor
EF = emission factor

The **activity factors** are the population of emitting equipment's such as length of pipelines from different materials used in gas distribution grids, the pressure of the pipelines, the number of service lines or distribution stations.

The **emission factors** are defined as the quantity of Methane emitted from each emitting source. Some can be evaluated on the basis of estimating the emissions from incidents in the grid. Other are based on the measurement of the fugitive emissions characteristics per kilometre of pipeline, material and pressure class.

4.3. Evaluation of the quality of the data set

In the period between 2013-2015, 9 companies provided data: the declared categories are summarized in Table 1:

Legend

	Value declared or 0
	Nothing declared

	Companies										
	A1	A2	A3	B	C	D	E	F	G	H	I
Grey cast iron											
Ductile cast iron											
Steel											
Polyethylene											
PVC											
Not specified											
Service lines											
City Gates											

Table 1: Datasets distribution

The companies that have declared data, have declared most of the fields (about 80% of requested field declared)

The declaring companies are representing 870.000 km of pipelines which is roughly corresponding to 50% of the EU 28 distribution pipeline length. If 80% of the fields have been declared, the full set could be considered as representative, allowing to apply the first scenario (see §4.4.1).

4.4. Emission factors distribution networks

4.4.1. Correlation

The analysis has confirmed, with a more complete dataset the assumption made in 2014 and the total emission were derived as a first approach from a first order polynomial in which the total Methane emission was calculated directly from the total pipeline length. In this report, a second approach has been developed considering 3 different sets of activity and emission factors related to:

- The length of the pipelines with a subdivision of the pipeline materials.
- The number of City Gates / pressure regulating stations
- The number of Service Lines were the distribution grid is connected to the households and the industry.

In the 2014 report 4 scenarios were distinguished, i.e.:

- 1) **Average emission factor** in which the emission factor is derived as the average factor from polynomial fitting including uncertainty of the coefficients.
- 2) **Median emission factor** in which the emission factors is calculated as the median emission factor of the sample population.
- 3) **Worst case emission factor** where the largest emission factors from the sample population is used for the estimation of the Methane emission.
- 4) **Most representative emission** factor, in which the most representative values are used. These are from the companies who delivered complete datasets.

The average emission factors and 95% UCL (upper Control Limit) (see §5) of this emission factors are finally found to be the more efficient for this second study.

The correlation of the CH₄ emission with the pipeline total length without distinction of pipe material is only of 51%, the second approach will be used (see §4.4.2), this is a TIER 2 approach.

If the declared set could be representative in term on length or completeness, the correlation between the activity factors and the associated emissions are globally poor:

- as an example, the correlation between polyethylene emission and polyethylene pipeline declared length which is representing 51% of the declared distribution pipeline length is only of 57%.

Based on this fact, it has been decided to provide the following results on emission factors considering not only the average of the emission for each activity factors but also the 95% UCL.

The UCL is define such as, according to the available dataset, for a given activity factor value, the resulting emission will have a probability of 95% to be below the UCL, having say so the, 95% Upper Control Limit line factor is a reliable maximum of the activity factor (see following figures).

4.4.2. Analysis of the emission factors by pipeline materials

Emission factors were derived for different type of materials of the transmission grid. Different types of materials can have significant different emission factors. For example, grey cast iron is a material with large emission losses in the grid. Most distribution companies in the EU28 have replaced or are replacing, their gas grid grey cast iron fraction by more modern materials as polyethylene.

Cast iron

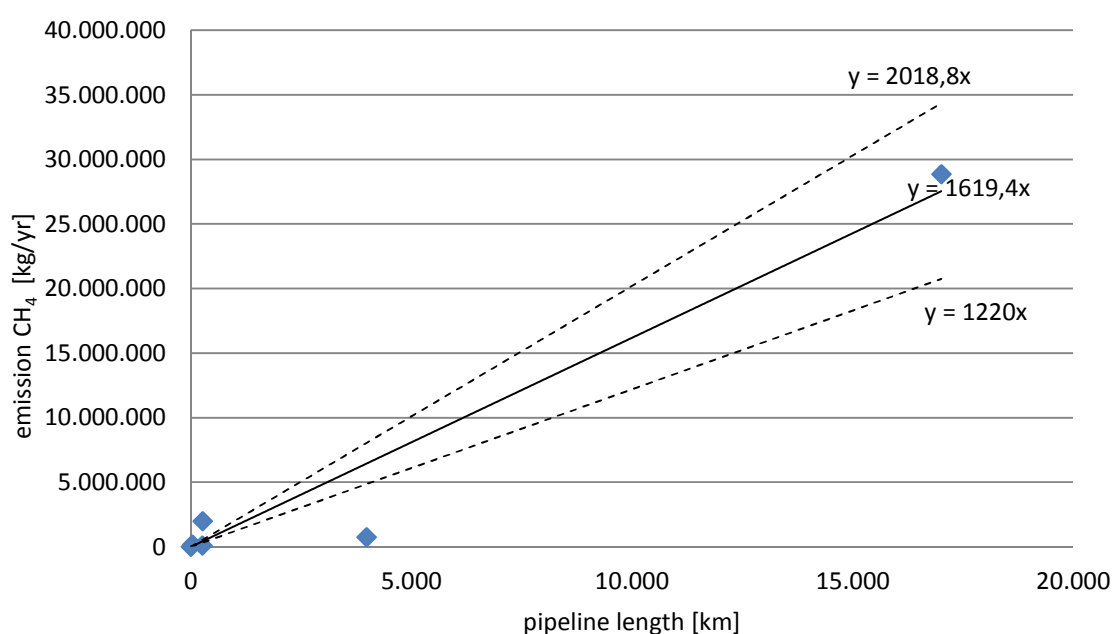


Figure 1: Regression analysis CH₄ emissions vs. grey cast iron pipelines length

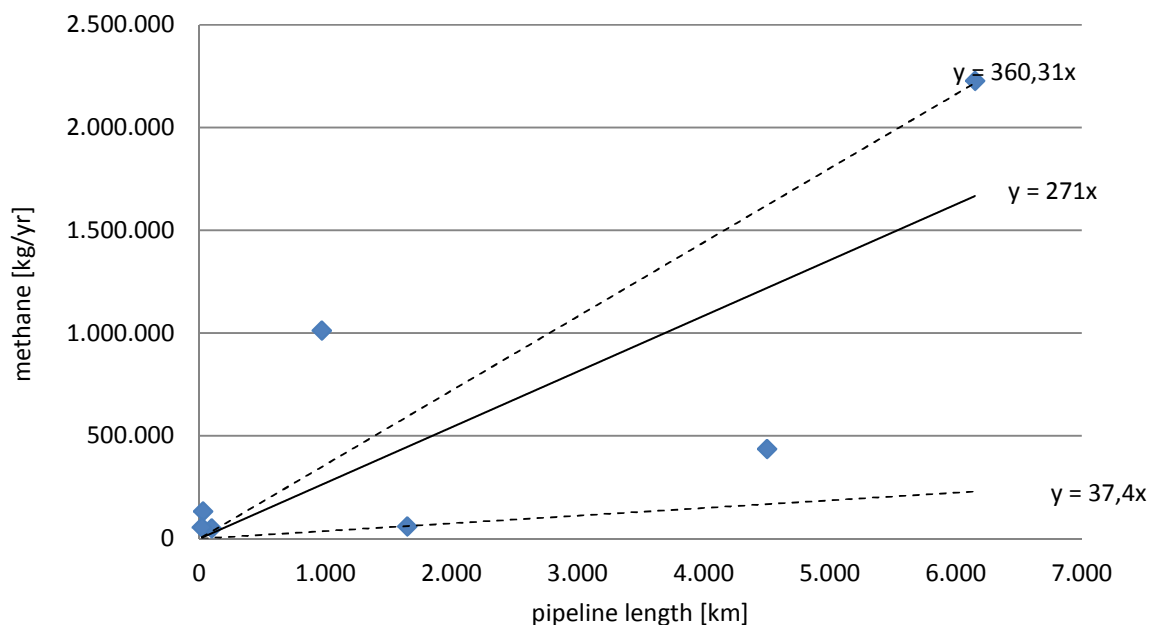


Figure 2: Regression analysis ductile cast iron CH₄ emission vs. pipeline length.

Material	Average emission factor	95% UCL
Grey cast iron	1.619 kg CH ₄ / km	2.019 CH ₄ / km
Ductile cast iron	198 kg CH ₄ / km	360 CH ₄ / km

Table 2: Emission factors for cast iron

As grey cast iron is representing 62% of the cast iron of the declaring company, we can derive the following emission factor for the cast iron in general:

Emission Factor cast iron average

$$= 0,62 * 1.619 + 0,38 * 198 = 1.079 \text{ kg CH}_4 / \text{km}$$

Emission Factor cast iron UCL

$$= 0,62 * 2019 + 0,38 * 360 = 1.388 \text{ kg CH}_4 / \text{km}$$

Grey cast iron has graphite flakes entwined with the rest of the structure, which create areas of weakness in the metal where fractures can begin that will split the metal. This form of the graphite flakes and the resulting propensity to fracture is why grey iron has low tensile and impact strength.

As a result, the pipe can be subject to a “guillotine fracture” in case unauthorized movements are applied, f.i. by movements of soil, heavy traffic, heavy construction works. For such

reasons, the grey cast iron replacement at least in sensitive areas, is considered as best practice by European companies, most of them have already replaced their grey cast iron network by more suitable material. Only 2,5% in length of cast iron is remaining in the EU28 distribution grid.

A further possible weakness of those pipes is their coupling: it can be made by a sleeve using cord and lead or with a rubber sleeve. If no injections of moisture are realized, the transition from city gas to dry natural gas leads to shrinking of the cord and possible emissions at the joints. Since the elasticity of the grey cast iron pipe is very low, there is a risk of movement at the connection, and thus of more leaking.

Ways to limit those emissions are possible: fine pressure regulation, monitoring of the use of the ground, of ground movements and of heavy construction works near the pipes and replacing them if needed, moistening of the gas, deployment of internal sleeves,

In ductile cast iron, the graphite incrustations have a node form (created by using a small quantity of magnesium), eliminating the weaknesses typical for the presence of flakes. Compared to grey cast iron, ductile has better mechanical properties: tensile resistance ≥ 420 Mpa $v \geq 200$, elasticity limit ≥ 270 Mpa $v. \geq 50$, prolongation ≥ 10 % v 0%, modulus of elasticity ≥ 170.000 Mpa $v. \geq 110.000$. By this higher elasticity and tensile resistance most sources of emissions existing in case of grey cast iron are avoided.

This is explaining the difference in the 2 cast iron quality emission factors.

Steel

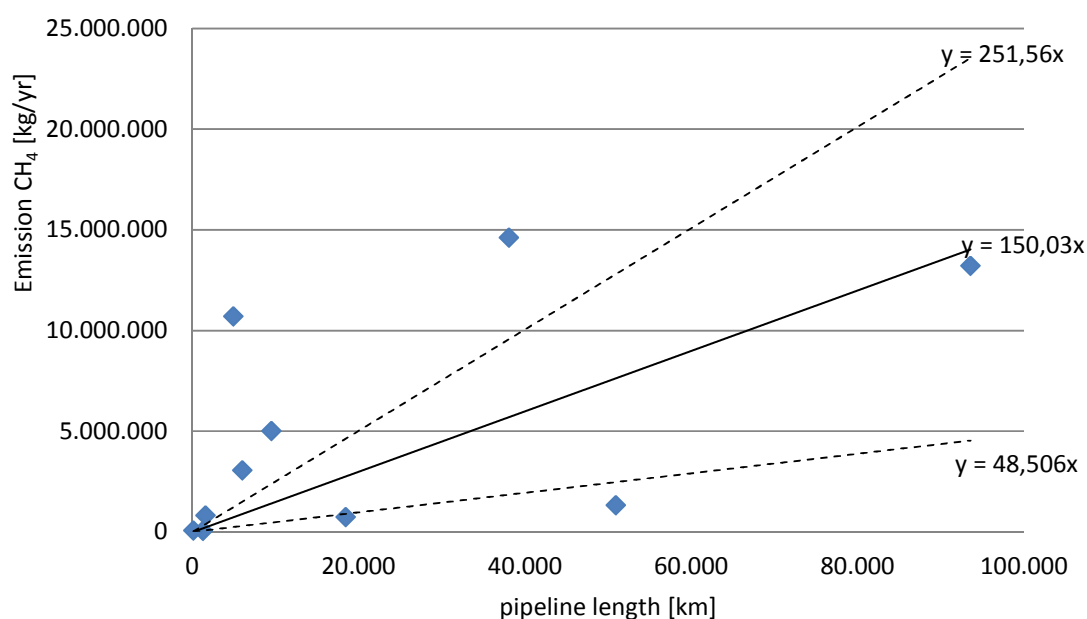


Figure 3: Regression analysis, steel CH₄ emission vs. pipeline length

Approximately 40% of the distribution grid is made of steel pipelines.

Material	Average emission factor	95% UCL
Steel	150 kg CH ₄ / km	252 CH ₄ / km

Table 3: Emission factors for steel

Polyethylene

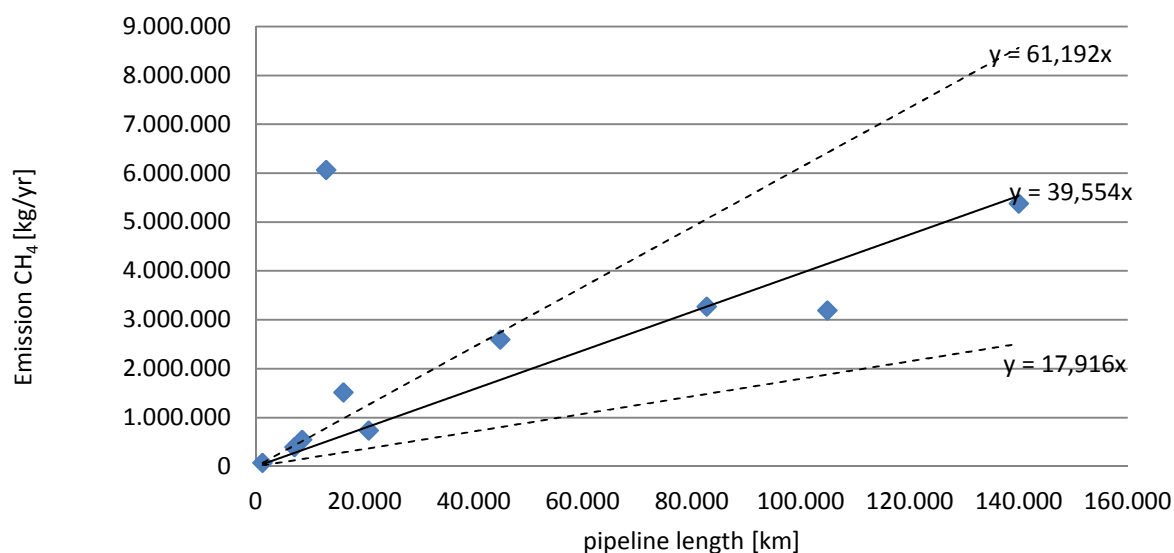


Figure 4: Regression analysis polyethylene (PE) CH₄ emission vs. pipeline length

The distribution grid in Europe consists of approximately 51% of polyethylene pipelines.

Material	Average emission factor	95% UCL
Polyethylene	40 kg CH ₄ / km	61 CH ₄ / km

Table 4: Emission factors for Polyethylene

PVC

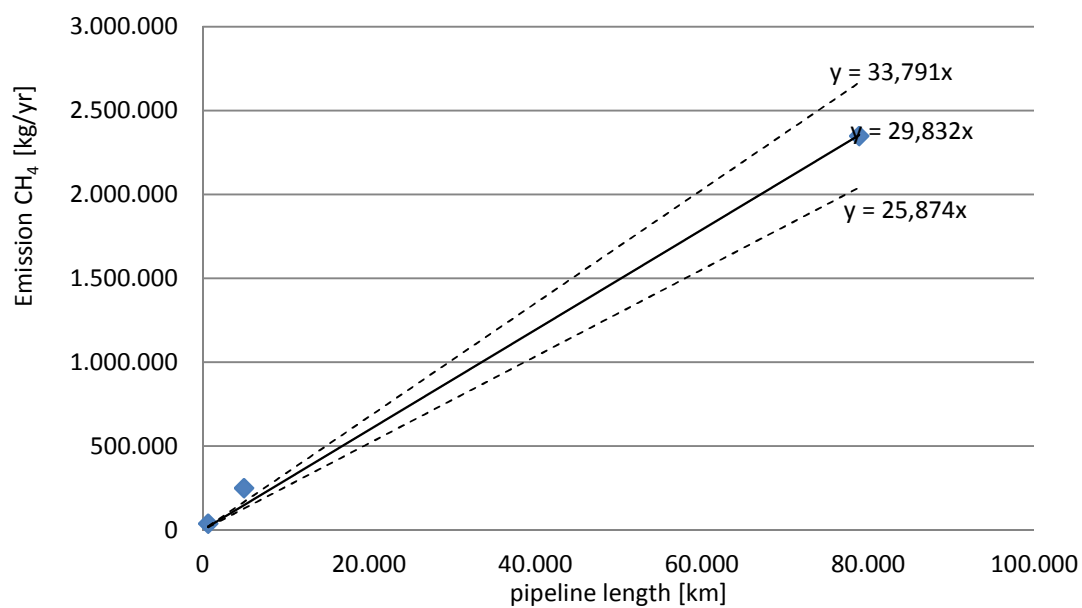


Figure 5: Regression analysis pipeline length PVC versus CH₄ emission.

Approximately 5% of the distribution grid is made of PVC pipelines.

Material	Average emission factor	95% UCL
PVC	30 kg CH ₄ / km	34 CH ₄ / km

Table 5: Emission factors for PVC

Not specified

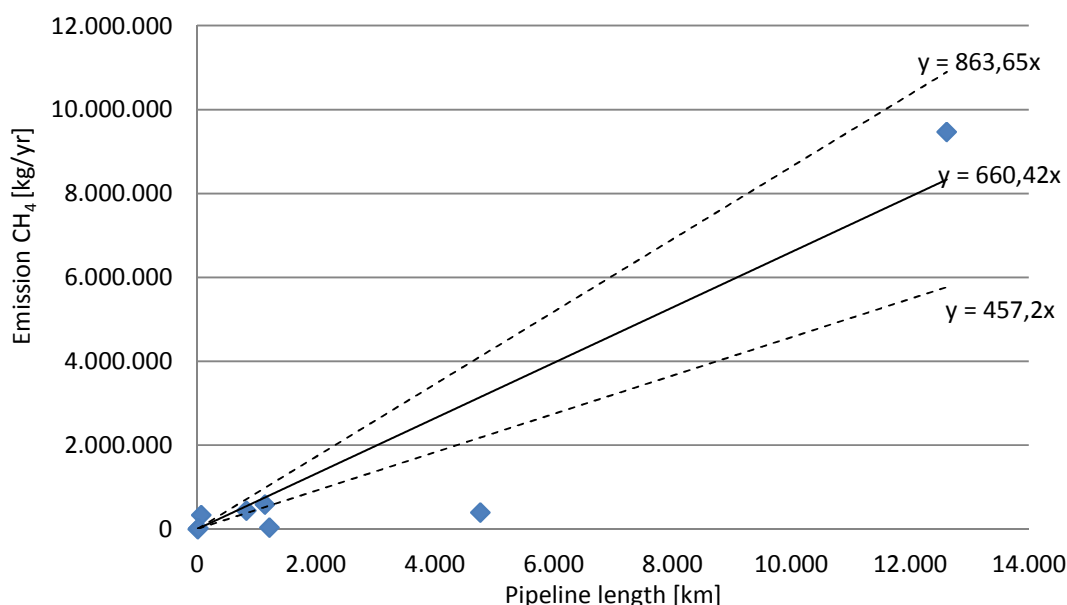


Figure 6: Regression analysis pipeline length 'not specified' vs. CH₄ emission.

In the questionnaire from MARCOGAZ also the length of the pipelines where the material is not specified can be given. The emission factors for these pipelines are estimated in [Table 6](#). The emission factors here are not allocated to a certain type of material. They are representing 2,4% of the pipeline length.

Material	Average emission factor	95% UCL
Not specified	660 kg CH ₄ / km	864 CH ₄ / km

Table 6: Emission factors for pipeline in the category not specified

4.4.3. Emission factors for service lines and City Gate stations

Service lines are the pipelines which connects the households and the industry to the main distribution grid. In the MARCOGAZ method the Methane emissions of the service lines are calculated from either the number of customers or as a percentage from the total emission from the pipeline grid of the operator. In [Table 7](#) the average emission factor from the datasets and the 95% UCL are given.

A similar approach is followed to calculate the emission factors from the City Gate stations. This emission factor is calculated from the number of City Gates. In [Table 7](#) the average emission factor from the City Gate stations and the 95 UCL are given. It has to be emphasized

that not all distribution grid operators do operate City Gate stations. In some cases, City Gate stations are operated by the national transmission companies.

Material	Average emission factor	95% Conf. Limit.
Service Lines	0,83 kg CH ₄ / customer	1,52 CH ₄ /customer
City Gates	198 kg CH ₄ / City Gate	360 CH ₄ / City Gate

Table 7: Emission factors for Service Lines and City Gate stations.

As explained previously, not all companies did deliver information from City Gate stations. Therefore, the datasets available for calculation was limited and caused a relative high standard deviation.

4.5. Activity factors EU28 distribution networks

To calculate emissions on a European level for distribution pipelines, Activity Factors on a European level are needed. In this report, Activity Factors are derived from different sources, but also from websites giving information about this issue. The three main sources used were the MARCOGAZ Statistics on the MARCOGAZ website, the available information from the Secretary of the International Gas Union Distribution Committee and the publications on the Eurogas website.

Country EU28	Distribution network length total (in km)	PE (km)	Steel (km)	Cast Iron (km)	PVC (km)	Other (km)	ref.	Connection points (#)	ref	City Gates (#)	ref
Austria	43.400	28.683	11.423	2	1.814	1.478	1	1.349.000	3		2
Belgium	71.609	52.561	16.971	430		1.647	1	3.156.000	1	190	2
Czech Republic	73.181	42.445	30.736	0	0	0	1	2.849.000	3	4.254	2
Denmark	18.229	15.677	2.552	0	0	0	1	421.117	2	502	2
Germany	498.500	254.235	218.343	11.964	13.958	0	1	20.979.000	3	49.119	report
Ireland	11.339	11.226	113	0	0	0	1	661.000	3	89	2
Italy	257.844	72.067	181.690	2.897		1.190	1	23.203.000	3	7.000	2
the Netherlands	125.000	21.250	18.750	3.750	78.750	2.500	1	7.152.000	3	1.009	2
Poland	170.900	68.360	102.540	0	0	0	1	6.852.000	3	751	2
Portugal	17.450	15.339	2.094	17	0	0	1	1.382.000	3	73	2
Slovakia	33.301	14.519	18.782	0	0	0	1	1.506.000	3	1.760	2
Spain	70.307	59.761	9.281	1.266	0	0	1	7.556.000	3		2
France	203.092	143.003	53.157	5.681		1.251	2	11.268.000	3	3.731	2
Finland	1.911	1.808	83	20		0	2	31.000	3	0	2
Slovenia⁽¹⁾	4.342	2.229	1.700	108	235	70	2	136.000	3	68	2
UK	126.335	81.657	7.242	17.362		20.074	2	23.184.315	2	49	2
Greece	6.087	4.663	1.281	136		0	2	325.000	3	24	2
Romania	17.218	8.958	8.260	0		0	2	1.408.170	2		
Cyprus	0	0	0	0	0	0		0	3		
Latvia⁽¹⁾	5.500	2.824	2.153	137	298	89	4	443.000	3		
Estonia⁽¹⁾	2.150	1.104	842	54	116	35	5	52.000	3		
Lithuania⁽¹⁾	8.300	4.261	3.249	207	449	134	6	562.000	3		
Croatia⁽¹⁾	18.386	9.439	7.197	458	996	296	7	647.000	3		
Malta⁽¹⁾	0	0	0	0	0	0		0	3		
Sweden⁽¹⁾	2.720	1.396	1.065	68	147	44	8	37.000	3		
Bulgaria⁽¹⁾	249	128	97	6	13	4	9	74.000	3		
Luxembourg⁽¹⁾	1.962	1.007	768	49	106	32	10	86.000	3		
Hungary⁽¹⁾	84.000	43.124	32.879	2.094	4.548	1.354	11	0	3		
Total	1.873.312	961.723	733.246	46.706	101.431	30.198		115.319.602		68.619	

(1) For all pipeline lengths were no material lengths were available the average distribution of the known data was assumed.

Table 8: Activity factors for EU28 DSOs

References	
1	Secretary of the International Gas Union Distribution Committee (available may 2017)
2	http://www.MARCOGAZ.org/index.php/statistics
3	http://www.eurogas.org/uploads/2016/flipbook/statistical-report-2015/mobile/index.html#p=10
4	http://www.kase.gov.lv/uploaded_files/Investor%20Presentation/Latvia-presentation_December_website.pdf http://www-pub.iaea.org/MTCD/publications/PDF/te_1541_web.pdf
5	https://www.mkm.ee/en/objectives-activities/energy-sector/gas-market
6	https://enmin.lrv.lt/en/sectoral-policy/natural-gas-sector
7	http://www.eesc.europa.eu/resources/docs/hupprezentacija1411.pdf
8	http://ei.se/Documents/Publikationer/rapporter_och_pm/Rapporter%202013/Ei_R2013_14.pdf
9	http://www.me.government.bg/files/useruploads/files/epsp/28.iii.2012.bg.sewrc.pdf
10	https://www.creos-net.lu/fileadmin/dokumente/downloads/rapport_annuels/pdf/gb_creos_facts_figures_2014.pdf
11	https://www.nve.no/Media/4864/3-c16-eqs-72-03_ceer-6thbr_ch5-7.pdf

Table 9: References DSO emission factors EU28

4.6. Methane Emissions for EU28 distribution networks

4.6.1. Emissions from distribution pipelines.

From the emission factors in §4.4.2 and the activity factors in §4.5 the total emission of the distribution grids of the EU28 are calculated. The calculations are performed for the average emission factors and their 95% UCL.

Pipeline material	Statistics	Emission factor	unit	activity EU28	unit	CH ₄ emission ton
Cast Iron	Average	1.079	kg/km	46.736	km	50.428
Steel		150		733.716		110.079
PE		40		962.339		38.064
PVC		30		101.496		3.028
Not specified		660		30.217		19.956
DSO pipelines		121		1.874.505		221.555

Table 10: EU28 Methane emissions from DSO pipelines (average)

Pipeline material	Statistics	Emission factor	unit	activity EU28	unit	CH ₄ emission ton
Cast Iron	95% conf	1.388	kg/km	46.736	km	64.870
Steel		252		733.716		184.574
PE		61		962.339		58.887
PVC		34		101.496		3.430
Not specified		864		30.217		26.097
DSO pipelines		184		1.874.505		337.857

Table 11: EU28 Methane emissions from DSO pipelines (95%UCL)

Figure 7 and Figure 8 gives the same information as given in Table 11 in a graphical representation

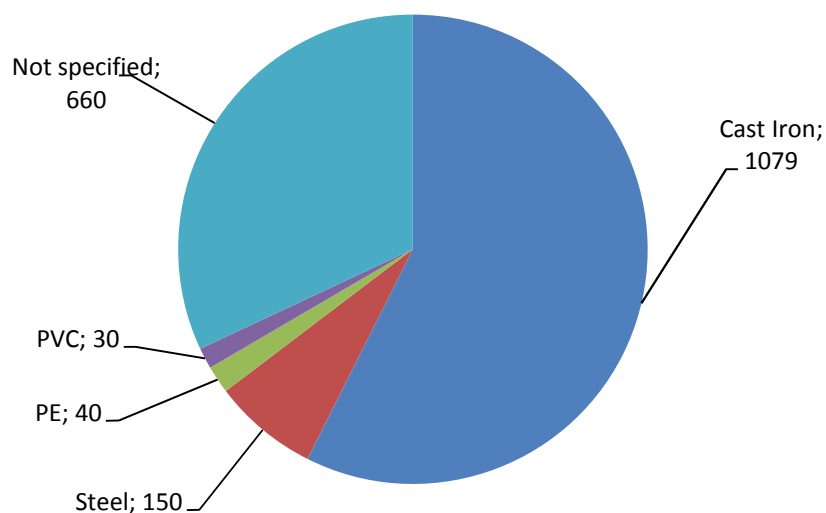


Figure 7: Average emission factors (in kg CH₄/km) distribution pipelines per type of material.

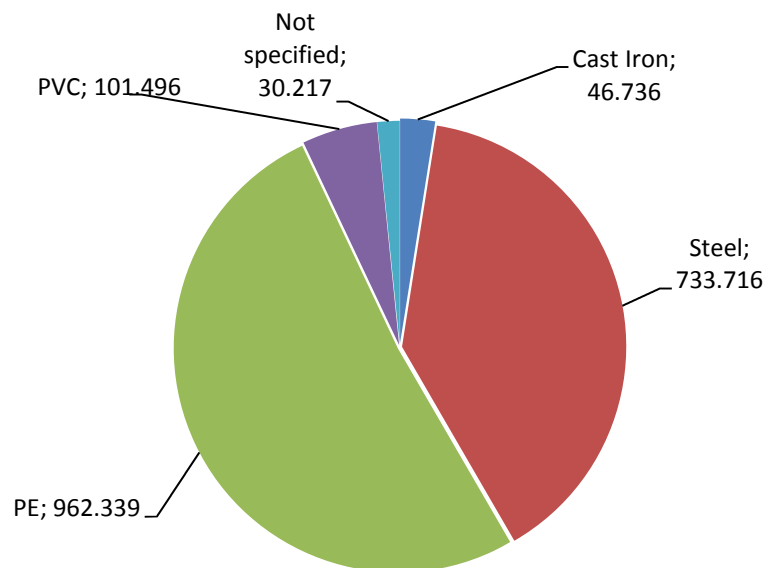


Figure 8: Distribution pipeline length (in km) per type of material

As a result of the relative large emission factors of cast iron and despite the relative small pipeline length (see [Figure 8](#)) the total emission of cast iron is approximately 24% of the total. In most countries distribution operators have a policy to replace grey cast iron networks by more modern materials with a better emission performance. Steel pipelines are responsible for about 48% of the CH₄ emissions from the distribution grid. Polyethylene covers approximately 1% of the total. Both steel and polyethylene cover respectively 39% and 5% of the length of the distribution network. When polyethylene covering 51% of the European network is only responsible for 17% of the methane emissions on the European distribution grid.

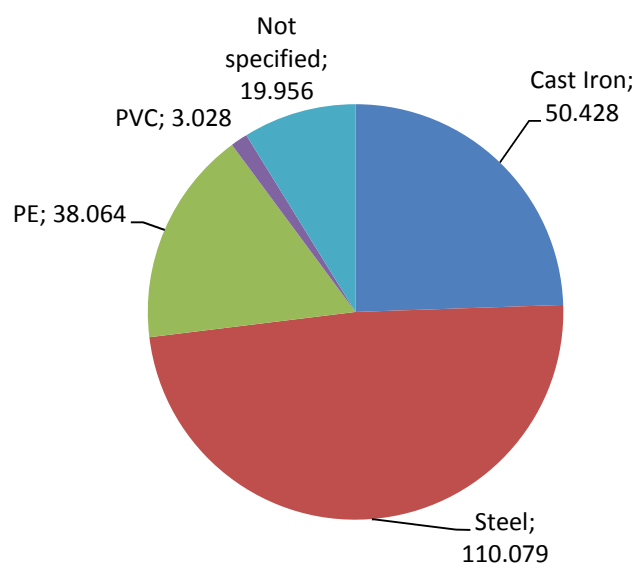


Figure 9: Distribution pipelines CH₄ emissions (in tons) EU28 per type of material.

4.6.2. Emissions from service lines and City Gate stations.

The estimated average EU28 emission from service lines and City Gate stations are given in the following tables also the 95% upper control limits of these emission are given.

Description	Statistics	Emission factor	Unit	Activity EU28	Unit	Emission [ton]
DSO Service lines (SL)	Average	0,83	kg/SL	115.750.602	# SL	96.544
DSO City Gates (CG)	Average	178	kg/CG	87.150	# CG	15.538

Table 12: Average emission factors for service lines and City Gate stations.

Description	Statistics	Emission factor	Unit	Activity EU28	Unit	Emission [ton]
DSO Service lines (SL)	95% conf	1,52		115.750.602	# SL	175.371
DSO City Gates (CG)		384		87.150	# CG	33.481

Table 13: Average emission factors for service lines and City Gate stations.

As stated below if considering the average emission factors, the EU28 emissions from distribution grid is 338.648 tons of CH₄, which means that service line emissions are representing 28,5% of the total emission, this is consistent with the results of the declaring companies (27,9%)

4.6.3. EU28 emission totals from distribution grids

From the tables in §4.6.1 and §4.6.2 the total emission from the EU28 and there 95% upper control limits are calculated. The results of this is given in Table 14 and Table 15. In this the emissions relative to the gas sales in the EU28 (EU28 inland gas sales: EUROGAS Statistical report 2015) and relative to the total anthropogenic CO₂ equivalents in the EU28 (Proxy GHG emission estimates for 2015, EEA report No 23/2016, page 76) are derived.

Description	Statistics	Emission factor	Unit	Activity EU28	Unit	Emission [ton]	Relative to sales	Relative to anthropogenic Methane emissions	Relative to EU28 CO ₂ eq
DSO pipelines	average	121	kg/km	1.874.505	Km	226.566	0,07%	1,23%	0,128%
DSO Service lines (SL)		0,83	kg/SL	115.750.602	# SL	96.544	0,03%	0,52%	0,055%
DSO City Gates (CG)		178	kg/CG	87.150	# CG	15.538	0,00%	0,08%	0,009%
Overall DSO						338.648	0,11%	1,83%	0,192%

Table 14: EU28 CH₄ emission DSO grids (Average)

Description	Statistics	Emission factor	Unit	Activity EU28	Unit	Emission [ton]	Relative to sales	Relative to anthropogenic Methane emissions	Relative to EU28 CO ₂ eq
Total pipelines	95% conf	184	kg/km	1.874.505	km	344.452	0,11%	1,86%	0,19%
DSO Service lines (SL)		1,52	0	115.750.602	# SL	175.371	0,05%	0,95%	0,10%
DSO City Gates (CG)		384	0	87.150	# CG	33.481	0,01%	0,18%	0,02%
Overall DSO						553.304	0,17%	2,99%	0,31%

Table 15: EU28 CH₄ emission DSO grids (95% UCL)

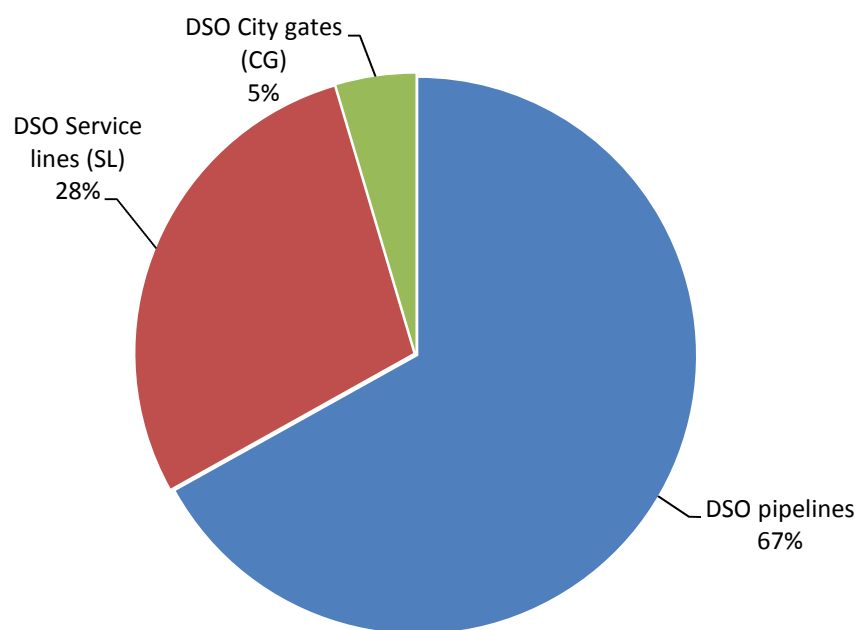


Figure 10: Distribution of CH₄ emissions depending on Activity factors in EU28

5. CONCLUSIONS

As a conclusion, a consistent dataset and complete dataset have been collected but low correlation between activity factors and emission factors was found. This is questioning the quality of the data and the way measurements are extrapolated locally. Considering this fact, the final results below are given, taking into account the emission factors issued from the average emissions but also from the UCLs (Upper Control Limit's), representing a maximization of the current CH₄ emissions on the EU28 distribution grids.

The distribution area has room for improvements. The ongoing research projects (GERG MEEM project) related to Methane fugitive emission estimations in distribution grid should enhance the situation for future reports. Some particular effort have to be made on the estimation of losses in the service lines regarding the importance of these data in the emission number. Nevertheless, this report is giving average and the UCL's of the CH₄ emission figures from EU28 distribution grid.

- ✓ The total estimated amount of Methane emissions from distribution grid is in the range of **339 – 553 kT Methane**.
- ✓ On that base, the methane emissions from distribution grids, expressed in CO₂ equivalent, are estimated to be in the range of **9.492 and 1.549 kT CO₂eq**⁶
- ✓ Considering these figures, the total distribution network losses ⁽⁷⁾⁽⁸⁾ are in the range of **0,1% to 0,2%**. In this figure, the losses of the grid but also the losses from service lines and the City Gate stations are included.
- ✓ The maximal yearly Methane emission rate on the EU28 distribution network is:

Pipeline material	Maximal emission rate	Share of the EU28 grid
Cast iron	1.388 kg CH ₄ / km	2,5 %
Steel	198 kg CH ₄ / km	39 %
Polyethylene	61 kg CH ₄ / km	51 %
P.V.C.	34 kg CH ₄ / km	5 %
Service lines	1,52 kg CH ₄ / customer	

⁶ GWP: Global Warming Potential; GWP100 of CH₄ (= 28) is used according to the Fifth Assessment Report (AR5) - IPCC.

⁷ Compared to the total of natural gas sales in Europe - EU28 inland gas sales: EUROGAS Statistical report 2015.

⁸ Please note that such a comparison is valid only at a European level, as, at a country level, not all the gas contained in the network at a moment in time will be sold in that particular country

- ✓ The total amount of GHG emissions caused by the Methane emissions from Natural Gas distribution grids is estimated to be **between 0,2% - 0,3%** of the total of anthropogenic⁹ GHG emission in Europe (EU28)¹⁰.

⁹ Anthropogenic emissions: emissions originating in human activity

¹⁰ Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015, EEA report No 23/2016, page 76

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- Fifth Assessment Report (AR5) - IPCC.
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- Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015, EEA report No 23/2016, page 76

7. APPENDIX

7.1. APPENDIX I: MARCOGAZ forms Methane emission

METHANE EMISSION Calculation for Distribution													
Organisation				Natural Gas Composition									
Company:		Name		Average Methane Content of Natural Gas:		81,3		%		(Vol.)			
Emissions for the Year:				Density of Methane:		0,7175		kg/m³					
Responsible Person:		Name		Conversion Factor from m³ Nat. gas to q CH4:		583,33		q CH4 / m³ Gas					
Calculation													
			Activity Factors		Emission Factors				Total Emissions		Source for own factor		
					Marcogaz Range*		Company						
No.	System Category	Pressure	Data	Unit	Minimum	Maximum	Data	Unit	m³/a	q/a	Measurement	Uncertainty	Estimation
Remark (please specify, if possible)													
1. Distribution Lines													
1.1.	Grey cast iron with lead joint	Low		km	M		M	m³/km	0,0E+00	0,0E+00			
		Medium		km	M		L	m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.2.	Ductile cast iron	Low		km	L		L	m³/km	0,0E+00	0,0E+00			
		Medium		km	M		L	m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.3.	Steel	Low		km	L		L	m³/km	0,0E+00	0,0E+00			
		Medium		km	L		L	m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.4.	Steel with cathodic protection	Low		km	L		L	m³/km	0,0E+00	0,0E+00			
		Medium		km	L		L	m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.5.	Steel without cathodic protection	Low		km	L		M	m³/km	0,0E+00	0,0E+00			
		Medium		km	M		M	m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.6.	Plastic Polyethylene PE	Low		km	L		M	m³/km	0,0E+00	0,0E+00			
		Medium		km	M		L	m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.7.	Plastic PVC	Low		km				m³/km	0,0E+00	0,0E+00			
		Medium		km				m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.8.	Material in general not specified	Low		km	M		M	m³/km	0,0E+00	0,0E+00			
		Medium		km	M		L	m³/km	0,0E+00	0,0E+00			
		(1)		km				m³/km	0,0E+00	0,0E+00			
1.9.	Total of Distribution Lines (1.1-1.8)								0,0E+00	0,0E+00			
2. Service Lines (2)													
2.1.	No. Of Customers		No.	M			M	m³/No./a	0,0E+00	0,0E+00			
2.	Percentage of Total of Distribution Lines	0,0E+00	m³/a	L			L	%	0,0E+00	0,0E+00			
2.	Total Emissions Service Lines								0,0E+00	0,0E+00			
3.													
3. City Gate and Customer Supply Stations for Metering and Regulating													
	Number of Stations		No.	M			M	m³/No./a	0,0E+00	0,0E+00			
4. Other (please specify)													
									0,0E+00	0,0E+00			
5. Total Emissions													
								Nat. Gas	0,0E+00	0,0E+00	Methane		
								Mio. m³	0,0	0	t/a		

7.2. APPENDIX II: MARCOGAZ members



7.1. APPENDIX III: EU28



Figure 11: EU28

GT-190300
10 Dec 2020

Quantifying leakage from underground pipelines

Phase 1



**Trust
Quality
Progress**



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GT-190300
10 Dec 2020

Quantifying leakage from underground pipelines

Phase 1

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Contents

	Contents	1
1	Summary	1
2	Project description	3
2.1	Introduction	3
2.2	Research questions	3
2.3	Approach of phase 1: Analysing, planning and recommendation	4
3	Measurements	5
3.1	Set-up	5
3.1.1	Site	5
3.1.2	Soil	6
3.1.3	Leaks	6
3.1.4	Installation and instrumentation	9
3.2	Results	10
3.3	Analysis	13
3.3.1	Systematic errors	13
3.3.2	Uncertainty	13
3.3.3	Impact of external conditions (weather)	13
3.3.4	Discussion	13
4	Campaign analysis	15
4.1	Dutch data set	15
4.2	General data sets	16
4.3	Measurement campaign advice	16
5	Conclusions	17
5.1	Measurements	17
5.2	Dutch leak data set	17
5.3	Campaign advice	17
6	References	19
I.	Calibration	20
II.	Simulation by particle diffusion	25
III.	Sample size	30
IV.	Proposed measurement protocol	35
V.	Historic Dutch suction measurements dataset	40



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1 Summary

Methane is a greenhouse gas that, when released into the atmosphere, contributes to climate change. The most important component in natural gas is methane. It is therefore important that the emissions of the gas sector are accurately and traceably quantified.

The estimation of the emission of underground pipelines is typically a process of two stages. One stage is executing a leak survey that identifies the location and number of leaks in the piping system. Secondly a number of reference leaks is selected of which the amount of leakage is quantified.

One of the methods available for quantification is the 'suction method', which is the topic of this report.

The uncertainty of the estimate of the total emission is determined by various factors, of which arguably the two most importance ones are the accuracy (systematic and statistic uncertainty) of the suction measurement and the statistical uncertainty in the average leaks flow rate (due to the limited sample size and the inherent variation of leaks flow rates occurring in the piping system).

This research describes the results of a set of suction measurements under controlled conditions, (i.e. known leak flow rate). The main findings are that a random error of less than $\pm 5\%$ is achievable and that the systematic error is possibly $\pm 15\%$. A possible source of the systematic error in this set of measurements is the long time to reach equilibrium suction condition. This leads to an overestimation of the leakage. It is expected that this systematic error can be reduced by carefully extraction gas out of the soil at larger distances around the leak. A suction measurement protocol is included in the report, taking this aspect, among others, into account. Other systematic errors are not yet fully excluded.

Suction measurement data set

From analysis of a historic Dutch dataset of suction measurements it appears that the standard deviation of each leak flow rate in the population of all leaks is about as large as the average. Further analysis (as well as a rule of thumb) suggests that about 20 measurements would be required to achieve a relative uncertainty of $\pm 25\%$ (with a relatively low confidence level of ca 0.8) in the estimate of the average leak flow rate.

Campaign advice

With regard to a measurement campaign the following recommendations are given:

- Use the suction measurement method according to protocol (annex II) to quantify the methane emission of selected leaks;
- The protocol must include removal of gas in a wide area around the leak;
- Expect to need about 20 leak flow rate measurements for each subcategory of leak type, in order to expect an accuracy in average leak flow rate estimate of 25%.

As the statistical uncertainty due to the variance of leaks flow rates in the field is larger than the uncertainty of the suction measurement, further development of the suction method is not urgently required. The suction measurement with a strict protocol to remove gas at larger distances from the leak is fit for its purpose. A direct way of improving the accuracy of the estimate of the amount of fugitive methane emission from buried gas distribution pipelines is to increase the number of suction measurements.

The suction method is inherently a relatively time consuming and thus expensive measurement. This precludes its application to all of the detected fugitive leaks. A



cost/benefit analysis could be used to determine the optimum number of leaks to be quantified, if more information on the variance in flow rate becomes available.

Therefore it is advised to implement a continuous measurement program, gradually covering all situations and gradually reducing the statistical uncertainties.

An additional advantage of a continuous program is that any change in the leak population (e.g. due to the aging of the network) is monitored and will become apparent. Also the attention to certain subcategories of leak types can be prioritized as warranted by intermediate results and for optimizing the measurement program. Analysis of the intermediate results should be part of the continuous program.

>



2 Project description

2.1 Introduction

Methane is a greenhouse gas that, when released into the atmosphere, contributes to climate change. The most important component in natural gas is methane. The GERG report "Analysing the Methods for Determination of Methane Emissions of the Gas Distribution Grid" contains an overview of European registration methods. Based on this overview, the development of a pan-European method is being conducted in a follow-up project "Development of an Accurate and Consistent Method for Methane Emission Estimation from the Gas Distribution Grid". In this GERG project various methods for the determination of methane emissions from, among other, underground pipelines have been identified and investigated.

Suction measurements to quantify underground leaks

For the quantification of the emission of methane from underground pipelines the method by suction sampling has been identified as widely used and effective. The measurement procedure consists of extracting a mixture of gas and air from the soil surrounding a leak using a high flow sampling technique and analysing the mixture to determine the leak flow rate of the underground leak. The measurement does not move any soil in the immediate neighbourhood of the leak and therefore has minimal influence on the leak flow rate.

A number of countries combine the results of a limited number of suction measurements with data of leak surveys to calculate an overall emission of the underground network of the mains.

Uncertainties in the current measurements

Current measurements show a large variation in leak flow rates. In high flow sampling techniques, variable soil conditions (e.g. cracks) and weather conditions (e.g. precipitation) potentially have a significant influence on the measurements. Also the factors Material, Pressure Level, Diameter and Age (or cause of the leak) and Soil Type (grain size) will have an influence.

As a result of these uncertainties, the latest GERG project on the development of a methane emission estimation method recommends to gain more knowledge and insight into underground leaks to get a more accurate estimate of the total emissions. This should lead to an European measurement program to quantify the underground leakages of pipes.

Objective

The main objective of the project of this report is to develop an European set of measurements of underground leakages to be used in a methane emission quantification method.

In order to reach that objective the following process with two phases is proposed: First the current set of measurements and the measurement method will be further analysed. Using this analysis a recommendation for a coordinated measurement program will be given which can be executed in a next phase. This report is about the first phase after which a Go/No Go decision is to be made.

2.2 Research questions

In this report - that covers phase 1 - the following research questions are addressed:

1. What is the accuracy of the suction method and how is this influenced by changes in the measurement protocol?
2. What is the influence of external conditions (wind, rainfall, soil) on the amount of leakage and the suction measurements?



3. What is the overall uncertainty in the average leak flow rate as expected from a given a set of well documented, suction measurements?

2.3 Approach of phase 1: Analysing, planning and recommendation

Statistics (analysis)

Describing the influencing factors by analysing the currently available set of measurements. The statistics will reveal the influence of factors such as pressure, material etc. The current uncertainty is identified by fitting the measurements to some parametrised statistical distribution functions.

Kiwa Technology has already developed a suitable statistical analysis method. A preliminary application of this method shows that the uncertainty in the population average of the estimated leak flow rate is significant (up to a factor 2).

As a consequence the calculated emission estimate also bears a significant uncertainty.

The effect of variations in the suction measurement method (such as the amount of air flow and position of sampling rods and wait time to steady state) will also be included in the analysis e.g. by means of computer modelling (see annex).

Limited number of suction measurements (validation)

In order to ascertain the validity of the model assumptions a limited number of suctions measurement under controlled and carefully documented (weather and soil) conditions will be performed. For this part of the project two controlled leaks in two different types of soil will be constructed on the premises of Kiwa Technology. The pressure of the leaks was initially planned to be varied between 100 mbar and 4 bar as does the leak flow through the hole. Due to experimental issues only measurements with a fixed pressure of approximately 100 mbar have been done.

During the measurement period the influence of wind and rain was recorded.

The initial plan was to measure every two weeks both leaks using the suction method until a total of 10 measurements per leak had been conducted. However, during the execution of the program, it became apparent that the distances over which the leakage was dispersed in the soil was larger than expected and it was impossible to operate both leaks simultaneously. Eventually 14 measurements were done.

The results provide a limited validation of the effect of variations in measurement conditions and an accuracy assessment.

Also the reproducibility of the suction measurement method is identified and a detailed suction measurement procedure is given. This procedure can be used in the coordinated measurement program in phase 2(see annex).



3 Measurements

3.1 Set-up

3.1.1 Site

The site for the measurements is located at the premises of Kiwa Apeldoorn (Figure 1, Figure 2, Figure 3). The distance to the nearest building is ca 10 m. The building is single storey 5m high.

Adjacent to the site are some low scrubs (2.5 m) and at larger distance (20 m) there are trees and a multi-story building (10 m height).



Figure 1 Site location, top view (red rectangle) Situation date ca. 2015. Source: Google Maps.



Figure 2 Site location, side view (red rectangle).

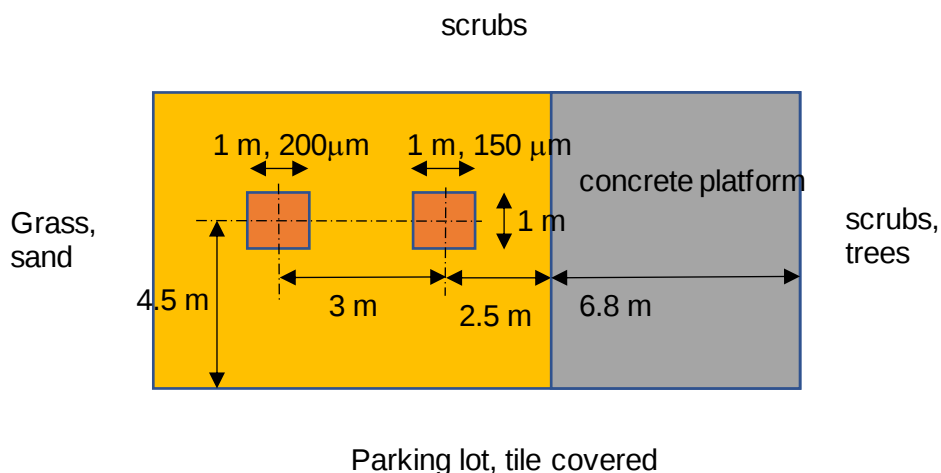


Figure 3 Site dimensions.

3.1.2 Soil

Two separate leak locations were prepared at the site. Each location comprises an area of approximate 1m x 1m filled to a depth of 1.5 m with sand of known and specified quality (see annex). The location was filled with 200 μm respectively 150 μm sand.

The sand was compacted in several stages during filling of the locations.

Several weeks after the initial filling of the locations, two small holes were dug, in which the leakage tubes were placed (Figure 8). The holes were filled again with the original sand and compacted manually in several stages.

3.1.3 Leaks

The leaks are constructed from copper tubing in which holes of various size are drilled (Figure 4, Figure 5, Figure 6). The tubes are made of 28mm copper pipes and are 30 cm long. A hole was selected in each of the four pipes that provided the desired approximate leakage at internal pressures between 30 and 200 mbar. The other holes were closed by soldering.



Figure 4 Set of pipes with various holes.



Figure 5 Detail of the pipe and a leak.

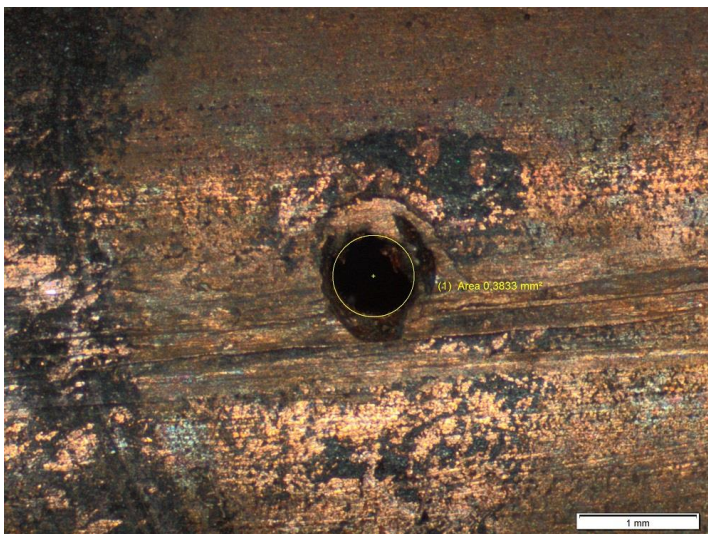


Figure 6 Detail of a leak hole. Macro photo with size indication (1 mm).

Due to imperfections of the drilling the leakage did not exactly correlate with bore diameter. The leakage was measured in a test box filled with the same soil as used at the test site. Leakage was measured as function of the pressure (for a typical result see Figure 7).

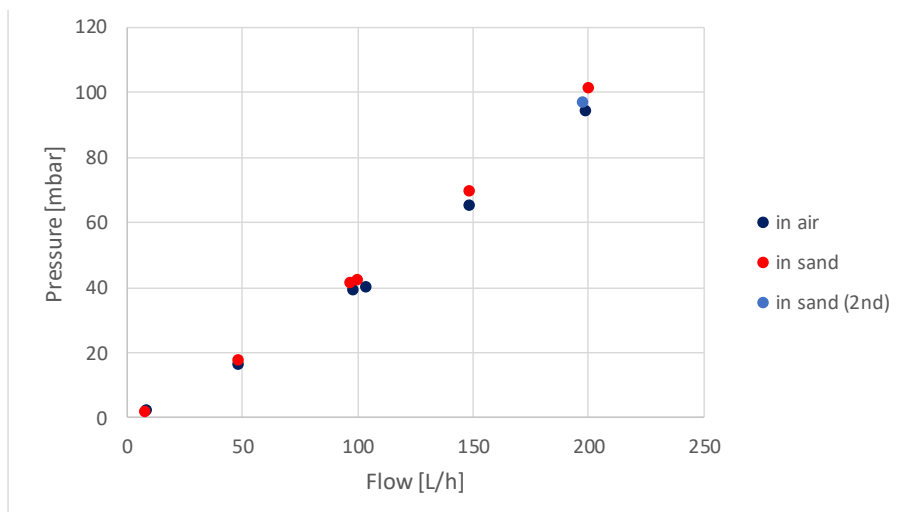


Figure 7 Typical relation between leak flow and pipe pressure. One measurement series of tube in open air (dark blue), a measurement series in sand (red) and a repeated experiment in sand with same tube buried and sand compacted again (light blue).

Care was taken to compactify the sand by applying pressure and adding and removing water. The repeatability of the effect of the sand burying the same leak several times was found to be limited. Most of the pressure loss occurs in the leak hole. The pressure loss in the sand is less than 10% of that value and varies with about a factor of 2 when repeating the experiment, as is apparent from comparison of the two typical measurement series in sand in figure 7. For example: at 200 L/h the leak pressure in open air the sand is 93 mbar and the two experiment with the buried leak show 97 and 102 mbar, a difference of 5 mbar respectively 10 mbar with the measurement in open air.

The relation between pressure and leakage is nearly linear, indicating that the flow through the leak behaves as laminar flow. This is a bit surprising, as the estimate Reynolds number at 200 L/h is about 7 000 (diameter 0.7 mm), which is well above the transition from laminar to turbulent in pipe flow as cited in the literature ($Re = 2900$). Possibly the length of the hole is not long enough to let the flow develop into turbulent flow.

The selected pipes are connected (Swagelok) to long flexible tubes ($\varnothing \frac{1}{4}$ ", 5 – 10 m). Two tubes are used for each pipe: one for the leak flow and one for pressure measurement.

At each leak site two pipes are buried side by side (Figure 8).



Figure 8 Positioning the leaking pipes in the soil (only a single one at a time was used).

3.1.4 Installation and instrumentation

For a detailed specification of the instruments used see table 1. A schematic of the installation is given in annex IV.

Instrument	Manufacturer	Type	Id.
Mass flow controller	Bronkhorst	FG-201CV-RAD-22-V-DA-000	M19213219B
Mass flow controller	Bronkhorst	FG-201CV-RAD-22-V-DA-000	M19213219A
Mass flow meter	Bronkhorst	F-106AZ-RAD-01-V	M19213219C
MFC control unit	Bronkhorst	E-8101-A-20-10-00	
Pressure regulator	Unknown	IR4015253 4PMX	330258
Pressure regulator	Unknown	IR4015250 4PMM	330268
Weather station (wind, temperature, precipitation, pressure)	Renkforce	WH2315	Not available
Suction pump	Esders	Vakumobil	156 – 07/13
Manifold + 9 valves	Kiwa		
Datalogger/PC	HP		
Methane monitor 1	Inficon	Irwin	
Methane monitor 2	Edinburg Sensors	Guardian NG	
Gas chromatograph	Interscience	Thermo Scientific Trace 1300 + TCD-detector	714530067

Table 1 Equipment used during the experiments.

The main measuring instruments are Bronkhorst mass flow controllers used in the monitoring mode. Two mass flow controllers (MFC) are used in the leak injection lines, continuously monitoring the gas flow in each of the leaks.

The leak gas flow is controlled by two pressure regulators.

Flow and pressure data was logged continuously during the duration of the experiments (sept – dec 2019) every 3 seconds.

Another high volume, low pressure drop mass flow controller was used to measure the total suction flow. Its data is logged during the actual measurement only.

The trend of the methane concentration in the suction mixture is measured using a Inficon Irwin methane detector. For the final measurement a Guardian NG of



Edinburg Sensors was used. The final sample in all the measurements is analysed with a gas chromatograph.

3.2 Results

The suction method was intended to be validated by measurements on two different leaks, emitting a known amount of methane, under a variety of weather conditions. During the validation of the suction method it became apparent at the first measurements that there was an unexplained excess of methane. Thus the planned set of measurements was changed to first identify the cause of the discrepancy. This was done by looking carefully at the possible source of systematic error and eliminating them as well as positively identifying the error.

Because the uncertainty of the suction method is largest with smaller leaks, the tests to identify the error were performed using the larger leak. The initial hypothesis was that an unknown leak source interfered with the measurements. No such source was detected. Another hypothesis was zero-drift of the methane sensor. Cross check with gas samples with a gas chromatograph did not indicate a zero-drift error. The final hypothesis was that gas that injected earlier contributed to the measurements, even after 6 h of suction and seemingly equilibrium conditions. Especially test 2810 indicated a very slow removal (> 48 h) of gas in the soil at distances larger than 2 m.

A final test provided the example picture of the situation (see Figure 9).

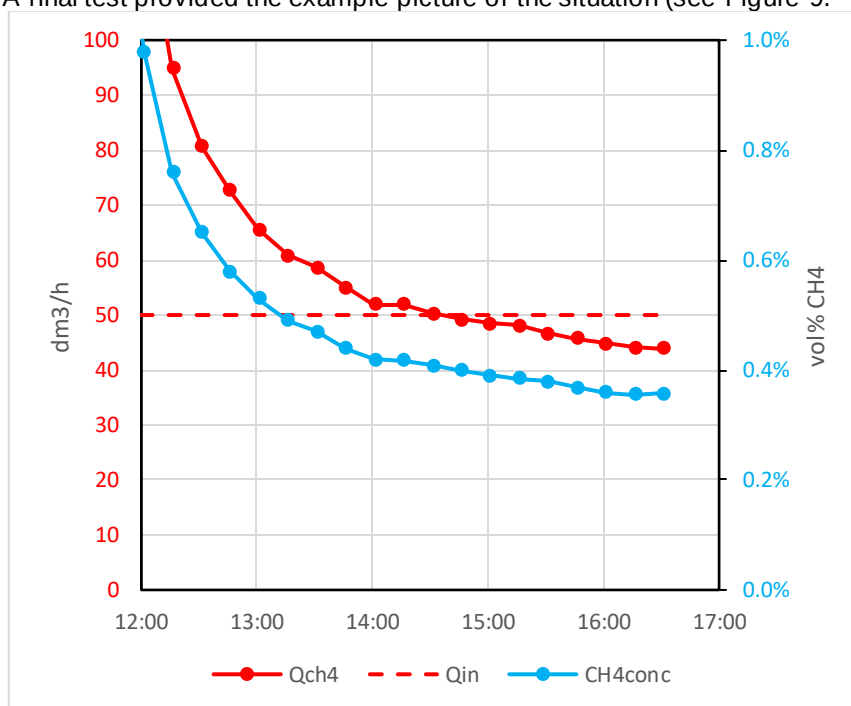


Figure 9 Suction flow as measured between begin and end of the measurement. Suction is terminated, according to protocol, at 16:30 when at two consecutive readings at 15 minutes interval no further decrease in concentration is registered. The suction was constant at 12 m³/h during the period.
Qch4: calculated leak flow rate from suction flow rate x CH4conc,
CH4conc: volume concentration methane in suction air

The number of measurements is necessarily limited and therefore it is hard to quantify all the effects, but the following observations summarize the tests:



- Weather conditions (rain, temperature) during the measurements or in the days before the measurement appear not to influence the detected leakage, indicating that any residual influence is less than 20%;
- Throttling the suction from 13 m³/h to 5 m³/h appears to decrease the detected leakage by 10%. Apparently a suction rate of 5 m³/h is not sufficient to capture all the leakage;
- Displacing all the 9 suction rods by 0.5 m from the leak appears to decrease the detected leakage by 10%;
- Suction for a significantly lower period than 6 h appears to decrease the detected leakage;
- Changing the suction depth from 0.5 m to 0.8 appears not to influence the detected leakage;
- The detected leakage appears (in most tests) to be systematically higher than the injected flow (10 – 20%), possibly indicating that equilibrium is not reached after nominal suction of 6 h;
- Initially the two leaks separated at 3m distance were operated simultaneously. After the first test the larger one was shut down. It cannot be excluded that the reservoir of that leak influenced the next few tests.

>



Measurement code	Protocol	Deviation		Remark
		$Q_{\text{suction}}/Q_{\text{in}}$ %	uncert. ±	
2009	Standard conf., no zero point correction conc. measurement	164.2	23.7	First measurement leak A, test of equipment (no GC measurement)
2509	Standard conf.	126.7	3.2	Check of repeatability leak A
2609	Standard conf, small leak	280.3	15.5	First measurement leak B
3009	Standard conf, small leak	268.0	18.5	Check of repeatability leak B
0210	Five rods only	133.0	3.6	Check for presence of additional gas source around leak A (influence of leak B)
0710	Five rods only, small leak	269.2	7.3	Check for presence of additional gas source around leak B (influence of leak A)
0910	Standard conf, 8 x 0.8 m depth, central rod at 0.5 m	121.3	2.7	Check of effect of suction depth (leak A)
1410	Standard conf, long measurement. Two samples: 0.74% after 6 h and 0.70% after 18h. Q_{in} fluctuates: 85 L/h at 6h, 92 L/h at 18h	93.5	2.0	Check of effect of long duration suction (leak A)
1710	Nine rods in circle at 0.7 m	111.4	2.4	Check for effect of different suction pattern (leak A)
2210	Standard pattern 0.5 m displaced, actual measurement only the 5 central rods used	95.6	13.8	Check for mispositioning of standard suction pattern (leak A) (no GC measurement)
2410	Standard conf (other leak closed). Nb conc fluctuated ca 10% and peaked around sampling	84.8	1.8	Standard suction measurement of leak A followed by check leak A closed and leak B physically closed. Inc carpetprobe measurement (8 x 0 ppm, 1 x 6 ppm)
2810	Control measurement with only 4 outside rods. Remark: after measurement the leak was closed and 24h later central rod sampled: 0.2% CH ₄ in sample during 1h!	7.2	0.2	Check for background around leak A (all leaks closed)
3110	Standard conf., reduced suction	108.2	4.7	Check for effect of reduced suction (leak A)
0611	Standard conf., reduced suction repeat measurement	98.6	4.4	Check of repeatability of measurement with reduced suction (leak A)
2204	Standard conf, fixed flow	88.6	2.0	Reference test with fixed flow (50 L/s) and new methane monitor

Table 2 Summary of measurement results (for standard configuration see Figure 29.(annex IV)



3.3 Analysis

In the next paragraphs the potential sources of error are listed. Conclusions are presented in 3.3.4.

3.3.1 Systematic errors

Systematic errors are the effects unaccounted for that compromise the accuracy of the measurement. The following potential sources of systematic error are identified:

1. Leakage between point of measurement of injected gas flow and leakage point in the soil. This would cause less gas to be extracted than assumed to be injected.
2. Methane content of the injected gas. The source of the gas is bottles of > 99.5% purity non-odorized methane.
3. Non-equilibrium between suction and injection. Before the actual measurement of the amount of leakage is taken, equilibrium between suction and injection must be established. Equilibrium is only reached asymptotically and the time constant depends on the amount of gas present in the soil and the amount of suction applied (see annex II).
4. Methane content of the extracted gas. The flow meter of the suction is calibrated with air. The methane content of the mixture causes an error (< 0.2% relative, see annex I).
5. Long and medium term drift of the sensors. The zero point of the flow and methane concentration measurement equipment is checked before and after each test and found to be negligible.

Any leakage between the tip of the suction rod and the suction flow measurement point will only be external air, due to the underpressure of the tubing and manifold. Therefore it has no effect on the calculated total amount of extracted methane.

3.3.2 Uncertainty

The measurement uncertainty is due to three main sources:

1. Uncertainty of the actual leak flow. The flow is measured using a mass flow controller (see annex)
2. Uncertainty of the methane concentration. The methane concentration is measured using a gas chromatograph (see annex I)
3. Uncertainty of the suction flow. The total suction flow is measured using a mass flow controller (see annex I)

For all instruments a calibration curve is available. The cited accuracy is treated as a random uncertainty and assumed to include the effect of temperature, variations in gas mixture (e.g. humidity) and other influences.

3.3.3 Impact of external conditions (weather)

The impact of external conditions is potentially twofold:

1. The flow resistance of the soil changes. As the leakage is pressure controlled this influences the leakage flow
2. The flow pattern changes, due to changes in ground water level and local saturation. On a somewhat larger time scale bacterial activity can block the gas flow locally and can even convert some methane in not measure carbon dioxide. This possibly influences the amount of not-extracted gas.

3.3.4 Discussion

During the suction procedure carpet probe measurements at the surface above the leaks and connection lines were occasionally performed. They showed no methane emission (<10 ppm), from which it is concluded that systematic error 1 (as listed in 3.3.1) is negligible at nominal suction.



The errors 2 and 4 contribute at most about 1% systematic uncertainty. For the systematic error 3 (non-equilibrium condition) there is no direct assessment, but simulations (see annex) indicate the possibility of an effect of more than 10%. Systematic drift of the instrumentation (error 5) is excluded.

Ad 3.3.2: The formulas used for calculation of the random uncertainty are well known and conventional (see annex I). These are used to obtain the uncertainties given in table 2. They are much smaller than the observed errors.

Ad 3.3.3: The injected volume of gas is measured during the suction tests. No variation in flow that correlated with actions (e.g. starting or stopping the suction, hammering the tubes in the soil, walking around the site) were observed, beside some incidental changes in pressure setting of the pressure regulators. This was random and apparently due to vibration and movement of the mechanical regulators. These changes were minor (<5%) and occurred only in the preparation phase of the measurement.

The major source of systematic error, and the one that can explain a measurement that is too high in the order of 10 – 20%, is that the suction process did not yet reach its equilibrium at the end of the test (after 5 – 6 h). This possibility is further confirmed by simulation (see annex).

It is observed that the error decreases during the months over which the test are taken. This is not fully explained, but could be due to the fact that the duration of gas injection prior to the actual test did vary per test, so the size of the 'gas reservoir' was not the same at the start of the various suction operations.

Based on this experience is it recommended to include in the test protocol a check to ensure that gas at a larger distances from the leak (between 3 – 5 m) is indeed removed.

Although it is plausible that the slow approach to equilibrium condition was the main cause of systematic error in these experiments, the tests do not prove the absence of other sources of systematic error. Further testing using a impermeably closed container with soil could give a more definitive proof.



4 Campaign analysis

4.1 Dutch data set

In the previous decades Kiwa has undertaken several small measurement campaigns with suction measurements on behalf of Netbeheer Nederland. These measurements are partly the basis for the estimate of average leak flow rate (as currently used as emission factor for the various types of .leak in the reported methane emission¹).

This is a dataset of 67 suction measurements, on nominal gas pressures between 30 mbar to 8 bar and various pipeline materials. Additionally concentration measurements with carpet probe are available. Generally no information of pipeline diameter or cause of the leak is available. Also location, soil and weather conditions are not directly available, although possibly to be retrieved when archived data sources are consulted.

As simple analysis provides the average leak flow rate of the various materials at the pressure stages of the Dutch network. As the number of measurements is very limited the standard deviation of the set of measurements can only be used as a rough indication of the uncertainty in the average leak flow rate.

It appears that the standard deviation is about as large as the average. As a rule of thumb this suggests that about 20 measurements would be required to achieve an relative uncertainty of +/- 25% (with a relatively low confidence level of ca 0.8) in the estimate of the average leak flow rate.

See Annex III for some more detailed analysis of how many measurements would be required to obtain a typical uncertainty, using a hypothetical leak flow rate distribution.

Nom.Pressure/Material	#	Avg (dm ³ _n /h)	Stdev (dm ³ _n /h)
30 mbar	18	123	128
AC	1	205	-
GCI	14	110	140
Nod. CI	3	161	67
70 mbar	1	46	-
GCI	1	46	-
100 mbar	29	60	116
AC	2	142	87
GCI	11	28	36
HPE	1	231	-
PE	2	49	69
u-PVC	4	172	275
m- PVC	6	15	12
Stell	3	19	11
1 bar	2	16	22
Nod CI	1	0	-
Nod CI (300mm)	1	31	-
3 bar	3	28	20
PE 63	1	49	-
PE80	2	17	11

¹ See e.g.: Methaanemissie door gasdistributie 2018 Netbeheer Nederland



4 bar	6	263	341
Nod CI	1	6	-
PE	3	268	367
PE 80	1	713	-
Steel	1	58	-
8 bar	8	451	730
Nod CI	1	581	-
PE100	1	0	-
Steel	6	504	836

Table 3 Analysis of data set suction measurements. Leak size in dm^3/h methane. 'Stdev' is the sample standard deviation.

4.2 General data sets

The analysis in annex III is valid for any European data set that is to be collected. And the results of the Dutch dataset might set a realistic expectation for the variability of leaks flow rates that occur.

Without introducing some physical and mechanical context it is fairly useless to speculate about the distribution of leak flow rates in a particular network. At least one should try and make a separation between various leak categories by cause (such as leak in a joint, corrosion or point load). The purpose of such a split is to provide a statistically homogeneous dataset for each of the various types of leaks. This would allow for a more smart combination of data from various networks and thus potentially improves the statistical uncertainty.

With sufficient empirical verification one could argue that the average leak flow rate is proportional to the (nominal) overpressure to a power of 0.5 or 1 (or a value in between). This would then allow to classify measurements of various pressures into the same category and to obtain a smaller confidence interval than using the separate data sets.

4.3 Measurement campaign advice

Based on the experience with the current experiments, the Dutch data set of suction measurement and the analysis presented in annex III, the following recommendations are given:

- Use the suction measurement according to protocol (annex II) to quantify the methane emission of selected leaks
- The protocol must include removal of gas in a wide area around leak
- Expect to need about 20 quantitative leak measurements for each subcategory of leak type, in order to expect an accuracy in average leak flow rate estimate of 25%

Considering the large variation in expected leak flow rates and the relative small contribution of the uncertainty of the individual suction measurement, further development of the suction method (although welcome) is not urgently required. A more direct way of improving the accuracy of the estimate of the amount of fugitive methane emission from buried gas distribution pipelines is to extend the dataset of suction measurements.

As the above recommendations implies a significant effort, it is advised to implement a continuous measurement program, gradually covering all situations and gradually reducing the statistical uncertainties.

An additional advantage of a continuous program is that any change in the leak population (e.g. due to the aging of the network) is monitored and will become apparent. Also the attention to certain subclasses of leak types can be prioritized as warranted by intermediate results and for optimizing the measurement program. Analysis of the intermediate results should be part of the continuous program.



5 Conclusions

5.1 Measurements

The uncertainty of the suction method is to be separated in a random and in a systematic component.

The random component consists of the uncertainties in the suction flow measurement and the concentration measurement and possibly intrinsic random variation of leakage during the measurement. Based on the specification of the equipment used and the calibration, the random uncertainty is estimated to be less than $\pm 5\%$.

The systematic uncertainty is dominant. An important source of systematic error is stopping the suction before equilibrium is reached. Simulations, extrapolation of measurement time series and comparison with known leakage suggest possible systematic errors in the order of $10\% - 20\%$.

From the measurements no indication of influence of weather and soil condition could be seen. Obviously, winter conditions with frozen soil are expected to compromise the measurement, but such condition were not part of this measurement program and are rather easily recognized and thus avoided in practice.

The measurement protocol has proven to be workable in its original form, although in hindsight a better control of the removal of gas in the soil at larger distance from the leak site appears to be required in order to reduce (the chance of) systematic error. The protocol (annex II) is adapted in this respect. With this protocol the suction method is fit for its purpose.

5.2 Dutch leak data set

It appears that the standard deviation of the leak flow rate in the population of all leaks is about as large as the average. As a rule of thumb this suggests that about 20 measurements would be required to achieve a relative uncertainty of $\pm 25\%$ (with a relatively low confidence level of ca 0.8) in the estimate of the average leak flow rate.

5.3 Campaign advice

With regard to a measurement campaign the following recommendations are given:

- Use the suction measurement method according to protocol (annex II) to quantify the methane emission of selected leaks;
- The protocol must include removal of gas in a wide area around leak;
- Expect to need about 20 quantitative leak measurements for each subcategory of leak type, in order to expect an accuracy in average leak size estimate of 25% .

As the statistical uncertainty due to the variance of leaks flow rates in the field is (much) larger than the uncertainty of the suction measurement, further development of the suction method is not urgently required. The suction measurement with a strict protocol to remove gas at larger distances from the leak is fit for purpose. A direct way of improving the accuracy of the estimate of the amount of fugitive methane emission from buried gas distribution pipelines is to increase the number of suction measurements.

The suction method is inherently a relatively time consuming and thus expensive measurement. This precludes its application to all of the detected fugitive leaks. A cost/benefit analysis could be used to determine the optimum number of leaks to be quantified, if more information on the variance in flow rate becomes available.



It is advised to implement a continuous measurement program, gradually covering all situations and gradually reducing the statistical uncertainties.

An additional advantage of a continuous program is that any change in the leak population (e.g. due to the aging of the network) is monitored and will become apparent. Also the attention to certain subclasses of leak types can be prioritized as warranted by intermediate results and for optimizing the measurement program . Analysis of the intermediate results should be part of the continuous program..

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6 References

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I. Calibration

Methane concentration (Gas chromatograph)

The GC used for the analysis of the gas is checked regularly and part of the calibration program of the chemical lab of Kiwa Technology.
The GC is calibrated using certified calibration gas mixture (example NG858: 0.8979 +/- 0.0045 mol% methane in air).
Correction for deviation of absolute pressure from reference conditions (1013.25 mbar) is applied.

For a mixture of 1 mol% methane in air a relative uncertainty of 1.3% is quoted (Bert Gerritsen personal communication 15 Oct 2019)

Suction flow (MFC)

F-106AI Mass Flow Meter
Model Key : F-106AZ-RAD-01-V
Productserie : IN-FLOW
Medium : Air (Lucht)
Range : 0.4...20 m³/h
Accuracy : ±1% full scale (at calibration conditions)

Methane injection (MFC)

Each leak is monitored by a mass flow controller.
The specification of the two MFC's is as follows:

MFC A

Model key : FG-201CV-RAD-22-V-DA-000
Serial number: M19213219A
Productserie : EL-FLOW Prestige
Medium : Mix: 81.3% CH₄ (Methaan) + 2.87% C₂H₆ (Ethaan) + 0.39% C₃H₈ (Propane) + 0.16% C₄H₁₀ #1 (Butane) + 0.05% C₅H₁₂ #3 (Pentane) + 14.33% N₂ (Stikstof) + 0.01% O₂ (Zuurstof) + 0.89% CO₂ (Koolstof dioxide) (mol %)
Range : 0.004...0.2 m³/h mixture = 0.005...0.2481 m³/h methane
Accuracy : ±(0.5% of measureant plus 0.1% v.d. full scale)(at calibration conditions)
Calibration certificate : 3-points calibration

The conversion factor from this gas mixture to pure methane is calculated using the conversion tool "Fluidat" provided by the manufacturer.

The full scale for pure methane of this MFC is 0.2481 m³/h.

MFC B

Model key : FG-201CV-RAD-22-V-DA-000
Serial number: M19213219B
Productserie : EL-FLOW Prestige
Medium : H₂ (hydrogen)
Range: 0.012...0.6 m³/h h₂ = 0.010...0.527 m³/h methane
Accuracy : ±(0.5% of measureant plus 0.1% v.d. full scale)(at calibration conditions)
Calibration certificate : 3-points calibration

The full scale for pure methane of this MFC is 0.527 m³/h.

For both MFCs the sensitivity for temperature and pressure is specified as zero:
< 0,02% FS/°C; span: < 0,025% Rd/°C and < 0,15% Rd/bar typical N₂; with pressure correction: < 0,02% Rd typical N₂

**Formulas used for uncertainty estimation.**

The relative accuracy A of a measurement is expressed as the ratio between the difference of the measured emission minus the applied injection divided by the applied injection:

$$A = \frac{Q_{suction} C_{methane}}{Q_{leak}} - 1$$

Therefore the uncertainty in the relative accuracy δA is related to the uncertainty in the primary measurements $\delta Q_{suction}$, $\delta C_{methane}$ and δQ_{leak} as:

$$\left(\frac{\delta A}{A+1}\right)^2 = \left(\frac{\delta Q_{suction}}{Q_{suction}}\right)^2 + \left(\frac{\delta Q_{leak}}{Q_{leak}}\right)^2 + \left(\frac{\delta C_{methane}}{C_{methane}}\right)^2$$

According to the information from the calibration, we take the uncertainties as:

$$\delta C_{methane} = 0.013 C_{methane,rd}$$

$$\delta Q_{suction} = 0.01 Q_{suction,fs} = 0.2 \text{ m}^3_n/h$$

$$\delta Q_{leak} = 0.005 Q_{leak,rd} + 0.001 Q_{leak,fs}$$

Where:

For MFC A: $Q_{leak,fs} = 0.2 \text{ m}^3_{nCH_4}/h$

For MFC B: $Q_{leak,fs} = 0.8 \text{ m}^3_{nCH_4}/h$

Note: the suction flow measurement is based on the calibration of air. No correction is made for the methane content. This introduces a systematic error. According to the manufacturer the relative error at 1 vol% methane is 0.2%, due to the different thermal properties of methane versus air.

Sand.

The grain size distribution of the sand used in the experiments is specified in the two reports below.

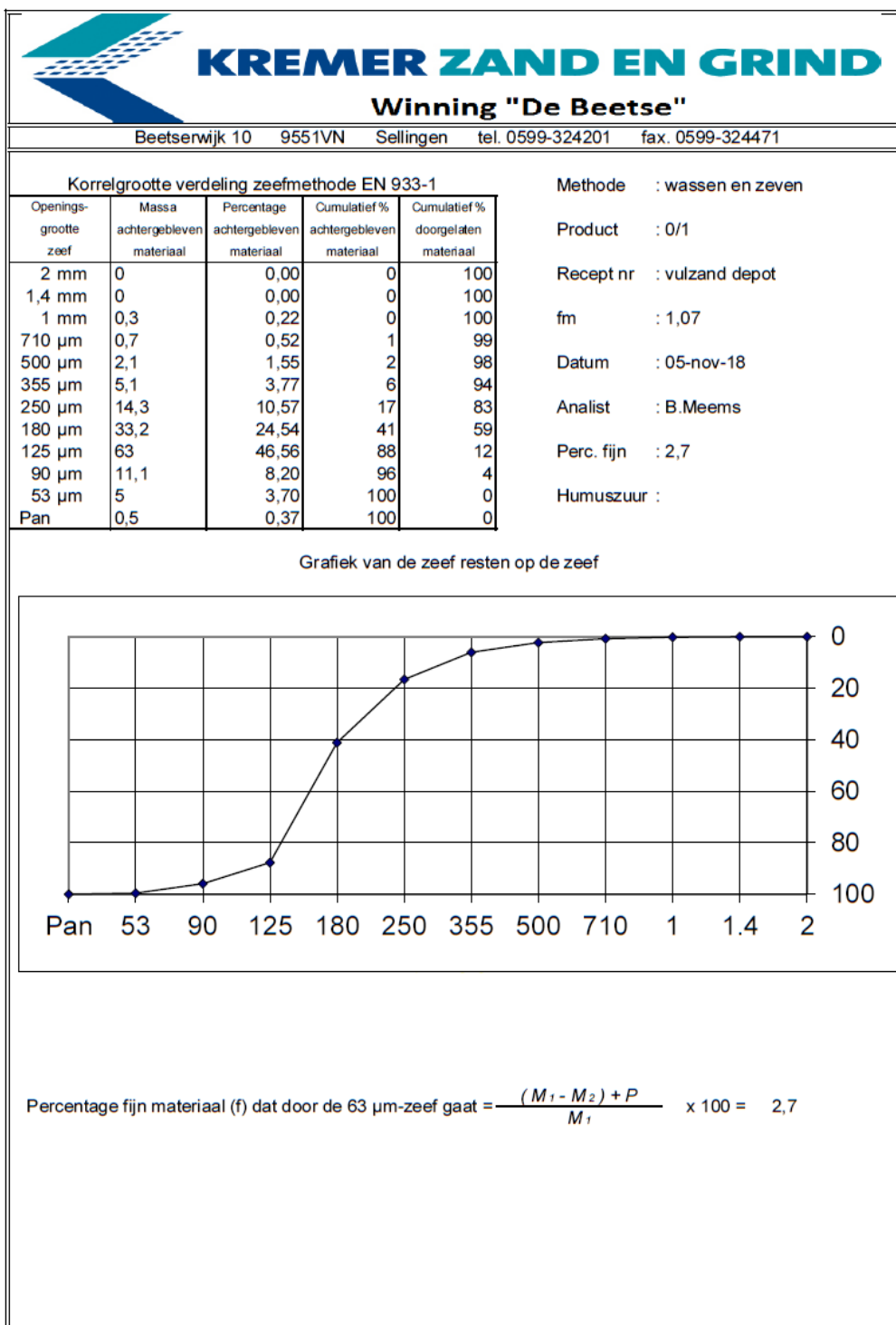


Figure 10 Specification of the batch of 150 µm grained sand

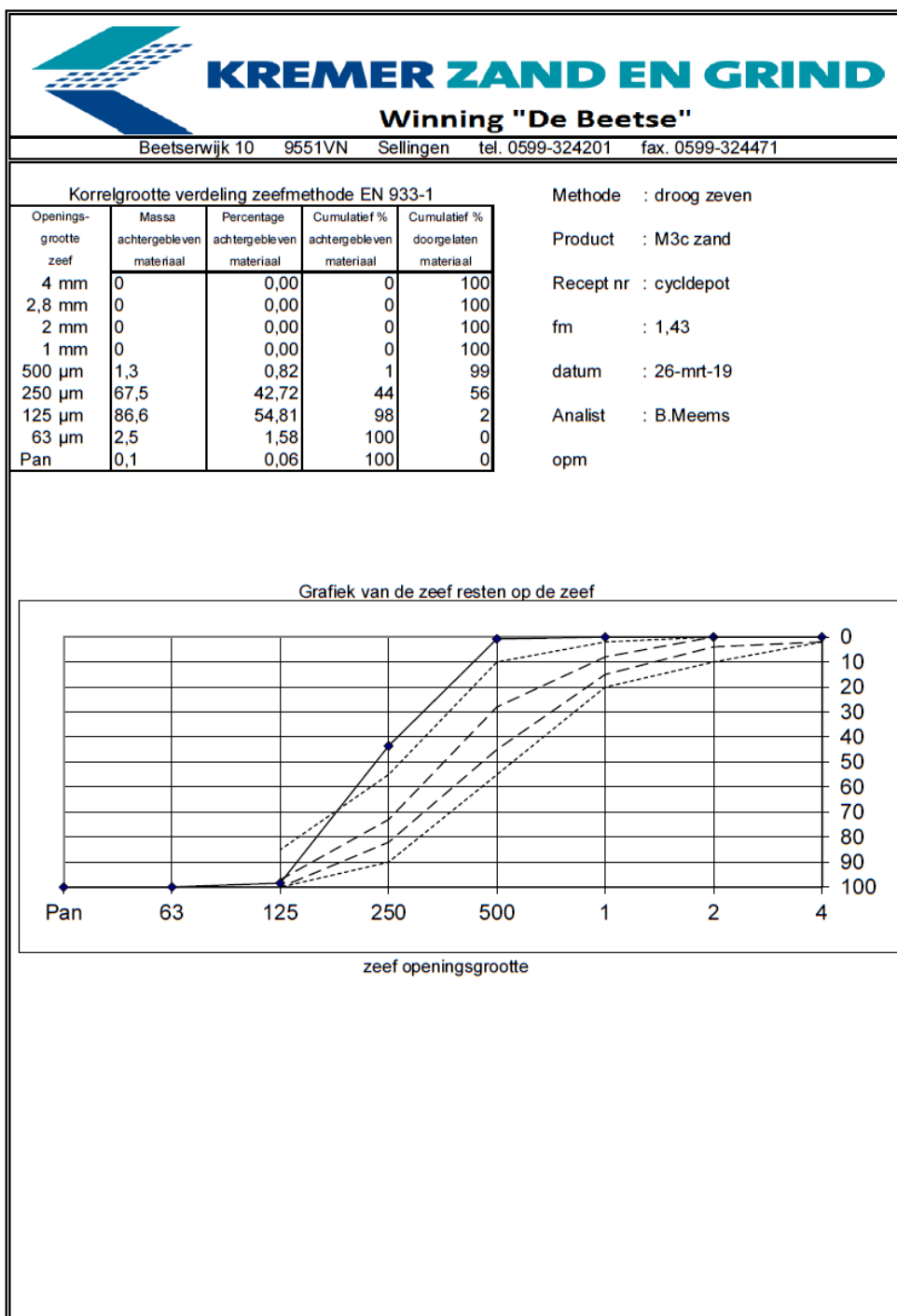


Figure 11 Specification of the 200 µm grained sand



Soil cone resistance test.

At 25 February Fugro B.V has performed a set of 11 manual sounding tests in the neighborhood of the leaks on the premises of the Kiwa test site. One of the 11 soundings did not return useful results, due to instability of the soil. In two soundings (nr 4 and 9) very small soil resistance was encountered in the top 1½ m of the soil. Debris in the soil was found in tests nr 3, 6, 7, 8 and 10, resulting in gaps in the measure profiles as the debris has to be removed to allow the deeper sounding to proceed.

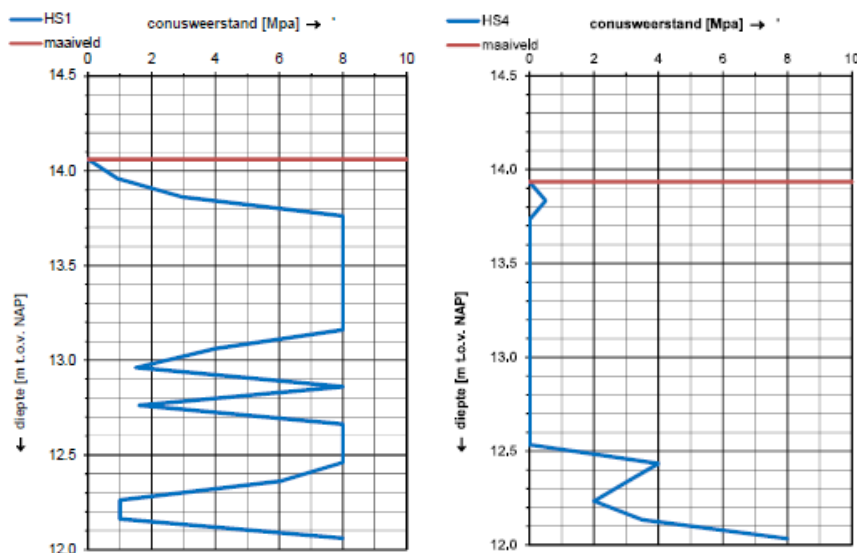


Figure 12 Typical cone resistance measurement (2 out of 10 available tests)

The soil was found to be variably compacted in layers. Resistance varied between 0 – 8 MPa as measured using a cone size of 1 cm².

Reference: Kiwa NL Monitoring terrein Apeldoorn, Rapportage Grondonderzoek
Fugro Report 1420-162976, 3-3-2020



II. Simulation by particle diffusion

In a typical suction measurement, gas/air mixture is extracted from soil at a constant rate until an equilibrium concentration is perceived to be reached. The value at the end of the suction process is used in the estimate of the leak rate. Some reasonable choice must be made, weighing the cost and duration of the measurement against a further reduction of error. There is some concern that a long tail of slowly decreasing gas concentration occurs during the extraction process, and that this masks, to the eyes of the experimenters, the real, lower equilibrium. In order to study the potential influence of a large reservoir of leaked gas around the leak that is being sampled in the course of the suction process, a numerical simulation was performed.

The simulation comprises a three-dimensional, time dependent simulation of gas flowing in a infinite disk of soil of 2 m thickness.

The leak is a point source of $0.108 \text{ m}^3/\text{h}$ in the centre of the disc at a depth of 0.8 m. The leak fills the initially gas-free soil during 10 days (240 h). After this period the suction starts, using one suction tube near the leak and four tubes around the leak (see figure). The suction points are located at 0.5 m depth and each tube evacuates $0.22 \text{ m}^3/\text{h}$.

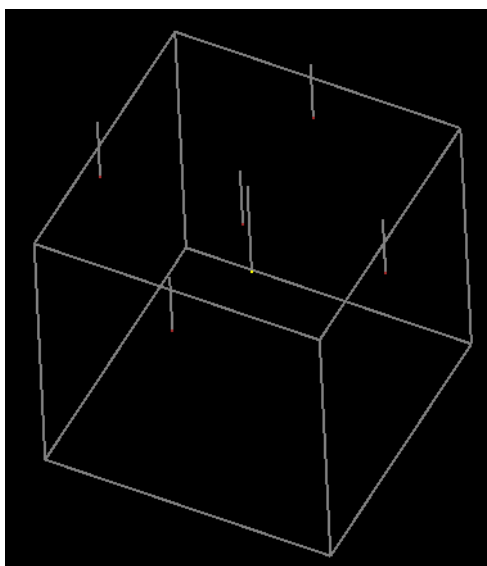


Figure 13 Schematic drawing of the location of the leak (0.8m depth, yellow dot) and the five suction points (0.5 m depth, red dots). The box is $2\text{ m} \times 2\text{ m} \times 2\text{ m}$ ($l \times w \times h$). The box and vertical white lines are for reference only.

Assuming a zero flow boundary condition at the bottom of the domain (the 'ground water table'), and a zero pressure at the top of the domain (the surface), incompressible flow and a uniform porous soil, the average streamlines can readily be calculated, using a set of positive and negative point sources, at suitably reflected positions with regard to the upper and lower domain boundaries that induces a potential (Darcy) flow. Additional to that deterministic flow, diffusion is simulated with a random walk Monte Carlo process of test particles, each representing a small volume of gas (typically 10^{-4} m^3).

As diffusion coefficient is taken the value of dilute methane in air. A correction is made for the effects of porosity and tortuosity of the soil. Typically the effective diffusion D_{eff} is calculated as:



$$D_{eff} = \frac{\epsilon}{\tau} D$$

Where ϵ is the porosity and τ the tortuosity. Both depend on the shape and sizes of the grains in the soil. For a porous bed of approximately spherical particles $\epsilon = 0.416$ and $\tau = 1.56$, $D = 0.21 \cdot 10^{-4} \text{ m}^2/\text{s}$ (Cornelia, 2000). This implies that the effective diffusion is about one quarter of the diffusion of the gas in air.

Distribution of gas in soil

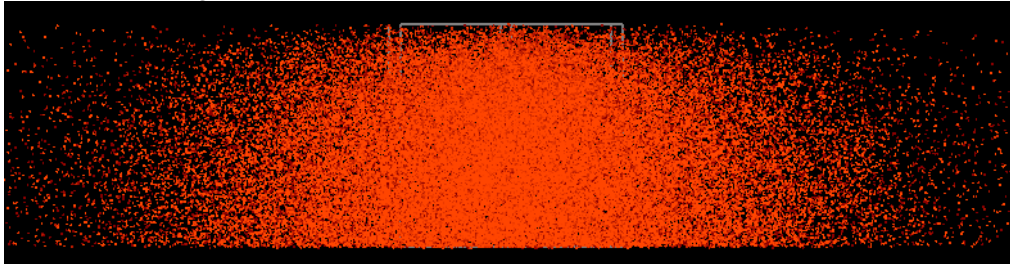


Figure 14 Distribution of gas in soil after 192 h continuous injection of $0.108 \text{ m}^3/\text{h}$. Side view of simulation of ca 92.000 particles. Box size is $2 \text{ m} \times 2 \text{ m} \times 2 \text{ m}$.

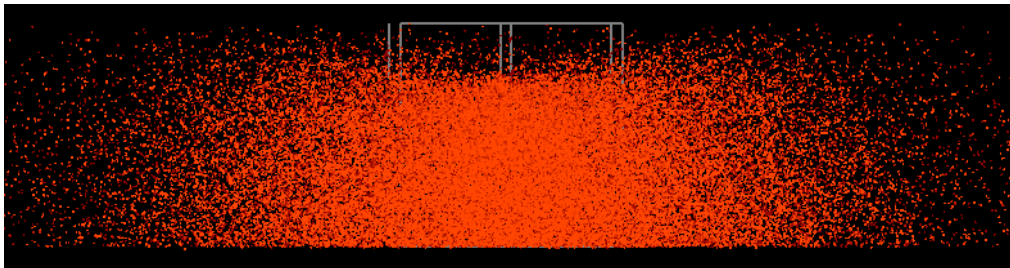


Figure 15 Distribution of gas in soil 0.5 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

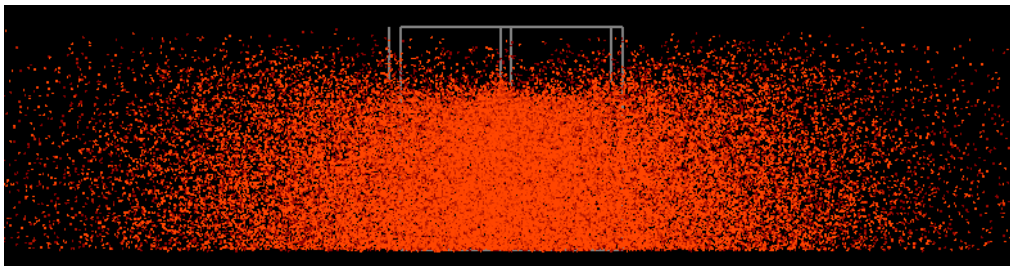


Figure 16 Distribution of gas in soil 1 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

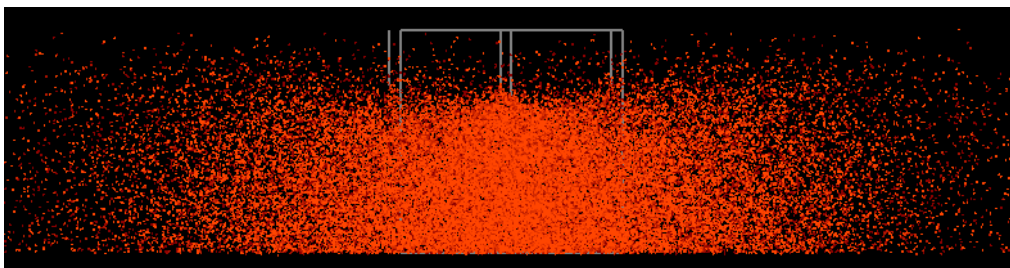


Figure 17 Distribution of gas in soil 2 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

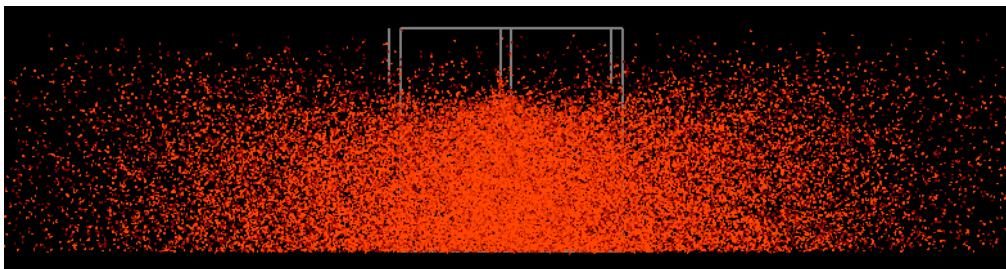


Figure 18 Distribution of gas in soil 3 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

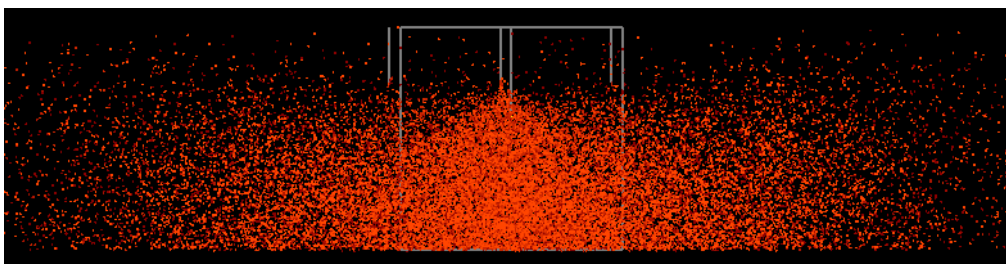


Figure 19 Distribution of gas in soil 6 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

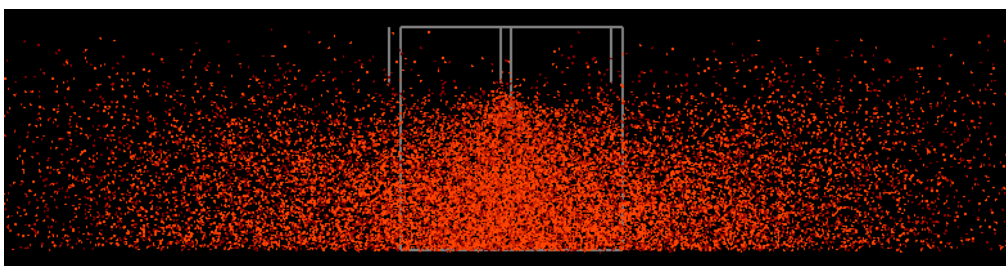


Figure 20 Distribution of gas in soil 9 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

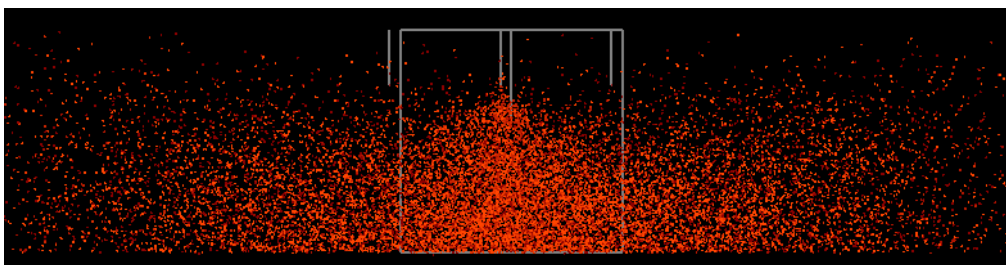


Figure 21 Distribution of gas in soil 12 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

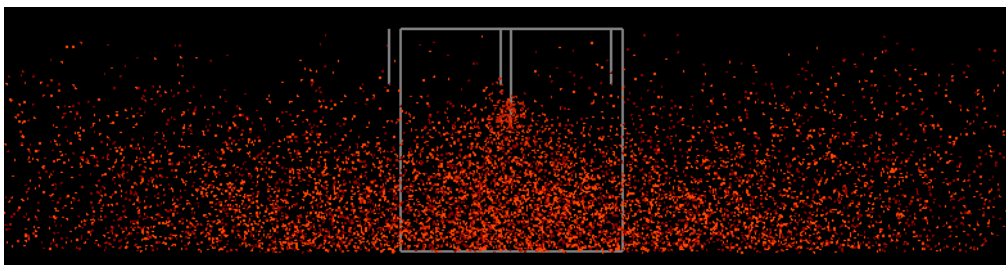


Figure 22 Distribution of gas in soil 21 h after start of suction ($5 \times 2.88 \text{ m}^3/\text{h}$)

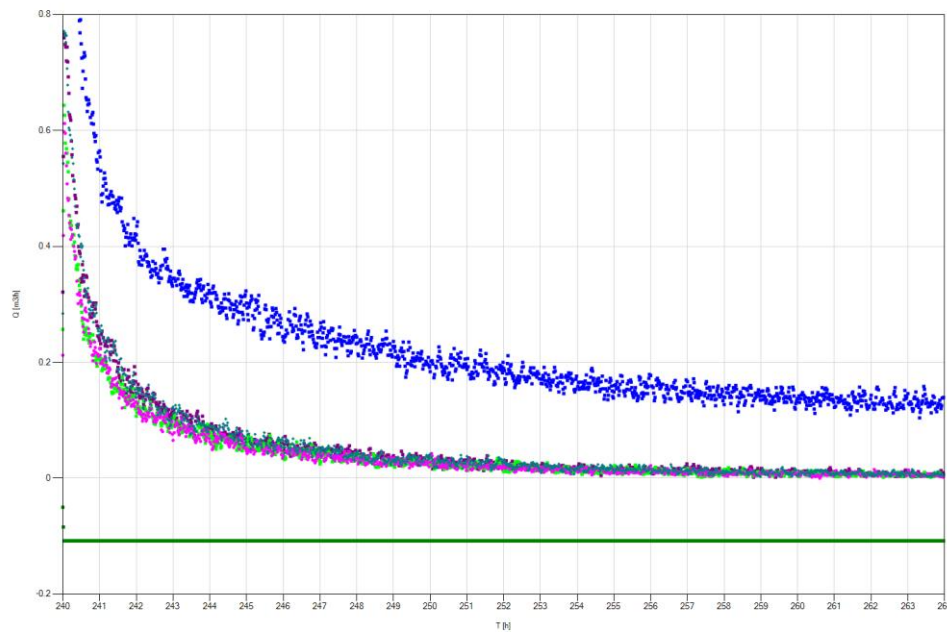


Figure 23 Injected gas flow (green line) and evacuated gas flow (blue and 4 other coloured markers). At equilibrium the sum of the blue + purple + violet + light green + sea green emission is equal to the negative value of the green line. A approximately 40% accuracy appears to be reached after about 24 h (see also next figure).

Note $T=0$ h is start of injection (leak), $T = 240$ h is start of suction.
Simulation ends at $T=264$ h.

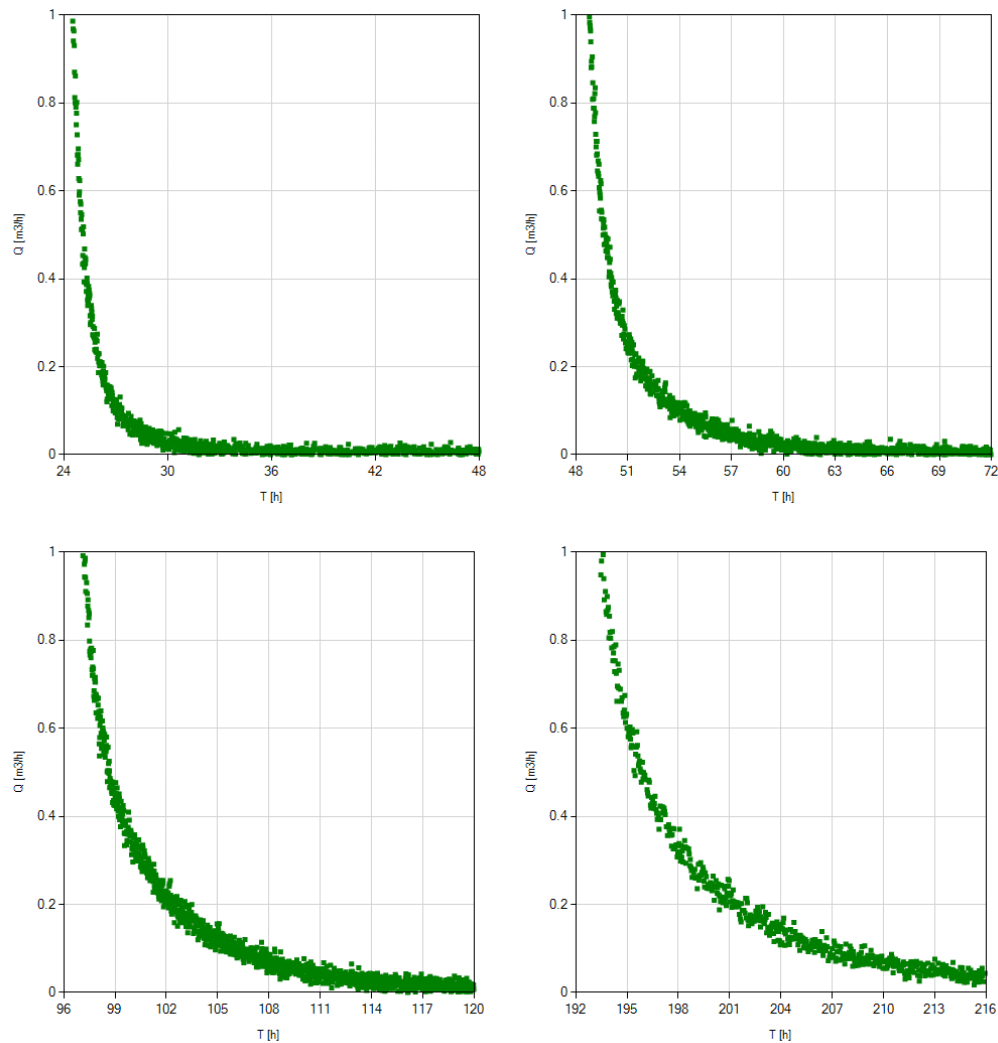


Figure 24 Imbalance between injection and suction (same scale as previous figure, but filtered over 5 minutes). Injection time before suction start: 24 h, 48 h, 96 h and 192 h.

Conclusion.

For the condition of the calculation, it appears that in this model even after a suction period of 24 h there is still a significant imbalance between injected and evacuated gas flow. The imbalance depends on the duration of injection before the suction starts and is apparently due to the reservoir of gas in the soil created during the injection period. In the case of an injection period of 8 days (192h) the imbalance after 24 h of total suction of 14.4 m³/h is still approximately 0.04 m³/h. This is 40% of the injection (0.108 m³/h)



III. Sample size

Two sources of uncertainty are of relevance for the determination of the average leak flow rate (WG_ME, 2019). These are:

- the uncertainty of the leak flow rate measurement itself
- the (unknown) distribution of the leak flow rates in the field.

Both uncertainties can be broken up in multiple parts. For the leak flow rate distribution in the field one would preferably distinguish between leaks of various causes, materials, diameters, gas pressure and environmental conditions (e.g. soil grain size, moisture content). The relevant assumption is that the set of leak data are a statistically homogenous group of data. Establishing and proving statistically homogeneity, however, is a challenge in itself and is not addressed here.

The uncertainty in average leak flow rate is reduced by increasing the number of independent samples. In principle, with the exclusion of the effect of systematic errors, the uncertainty in the average leak flow rate reduces, when a sufficient large number of samples is available, with the square root of the number of samples taken.

The detailed strategy of collecting an optimal variety of samples is the topic of phase 2 of the project. But to indicate the magnitude of this task we include in this annex some calculations of distributions and sample sizes with the associated uncertainty.

In these examples the measurement uncertainty is set to zero and only the effect of the shape and width of the distribution of leak flow rates is taken in consideration. With a non-zero measurement uncertainty the total uncertainty in the average leaks size is always larger.

Method.

A distribution of leak flow rates is specified. (e.g. a lognormal distribution with an average of 1 kgCO_{2eq}/h and a standard deviation of 50%).

A specified, relatively small amount, of samples (e.g. 10) is taken randomly from this distribution and their average is calculated. This procedure is repeated a large number of times (e.g. 100000)². This set of averages is in itself another distribution, of which the statistical properties (e.g. mean, median and 5percentile bounds) are taken. These properties reflect the uncertainty in experimental determination of the average leak flow rate using a given sample size and assuming a given leak flow rate distribution.

This is a theoretical exercise. If we knew the leak flow rate distribution there would be no need to perform measurements in the first place. If we would have physical and theoretical reasons to assume a certain family of distributions (e.g. lognormal), we could try a best fit of the parameters of this family (mean and standard deviation) to the measurements and reconstruct the expected mean leak flow rate. This would introduce additional uncertainty. For such a procedure the paradigm of Bayesian Statistics. (Lee, 2004) provides a suitable framework.

Example 1. Lognormal distribution (unimodal)

As leaks typically have only positive outflow, it make sense to assume a distribution with a positive support (0, +∞) only. A suitable distribution is a lognormal distribution. In this example we assume a lognormal distribution of a mean of 1 kgCO_{2eq}/h and a relative standard deviation of 50%. The PDF and CDF of this distribution are shown in the figure below.

² A similar method is also suggested in the annex of the Marcogaz report (WG_ME, 2019)

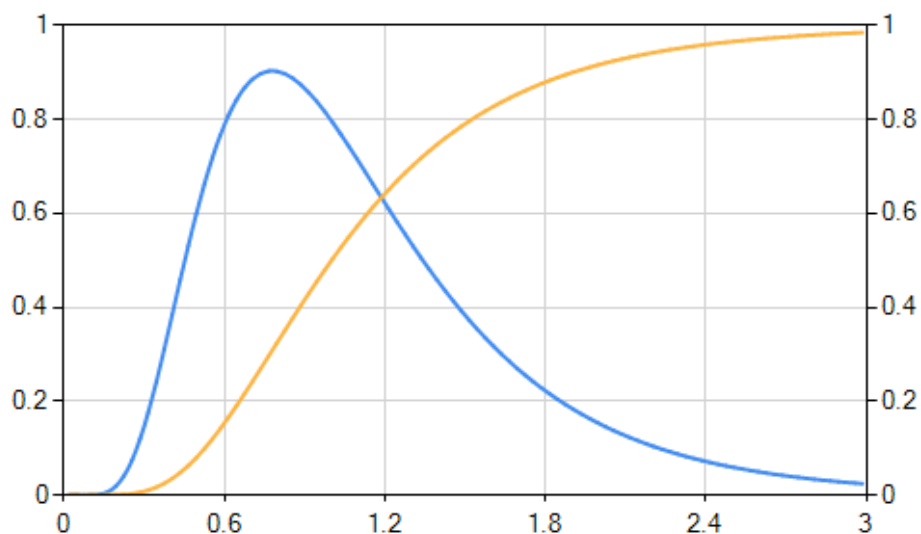


Figure 25 Assumed probability density function (blue) and cumulative distribution function of leak flow rates in a particular, statistically homogeneous set of leaks. Horizontal scale in kg/h.

Using this distribution the uncertainties in the estimate of the leak flow rate (which is 1.13 kg/h) for various samples sizes is given in the table below.

#Samples	1	3	10	30
<Average>	1.13	1.13	1.13	1.13
<Median>	1.00	1.08	1.12	1.13
<-5perc>	0.44	0.66	0.85	0.96
<+5perc>	2.28	1.78	1.47	1.32

Table 4. Statistics of the estimate of average leaks flow rate in $\text{kgCO}_2\text{eq/h}$ using #Samples, assuming the leak flow rate distribution of Figure 25 and 1 000 000 trials.

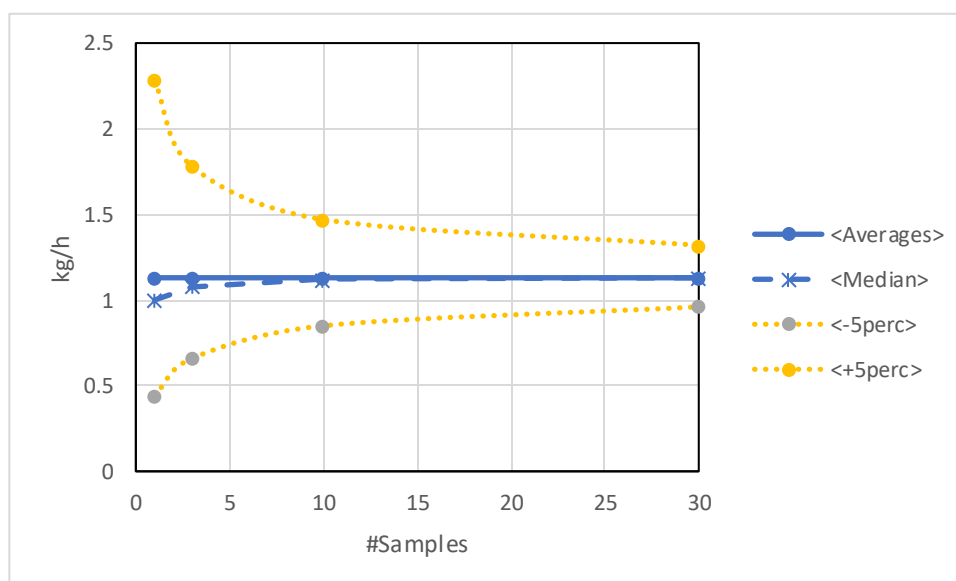


Figure 26 Statistics of the estimate of average leaks flow rate using #Samples, assuming the leak flow rate distribution of Figure 25.



The table and figure show that, with this assumed distribution, there are approximately 30 samples needed to obtain an estimate of the average leak flow rate with an uncertainty of about 15% and a confidence level of 90%.

Example 2. Sum of two lognormal distributions (bimodal)

Usually unimodal distributions are used and they are often intuitively preferred for reason of simplicity ('Occam razor').

Nevertheless, if there is more than a single physical mechanism that produces leaks, multi modal distributions become plausible. One can e.g. consider leaks due to corrosion and leaks at joints due to soil movement. A specific distribution can be associated with each cause (and there can exist some interaction too).

We therefore introduce an example where 80% of the, typically smaller, leaks follow one, relatively wide, lognormal distribution and 20%, typically larger leaks, follow another more narrow lognormal distribution (see figure),

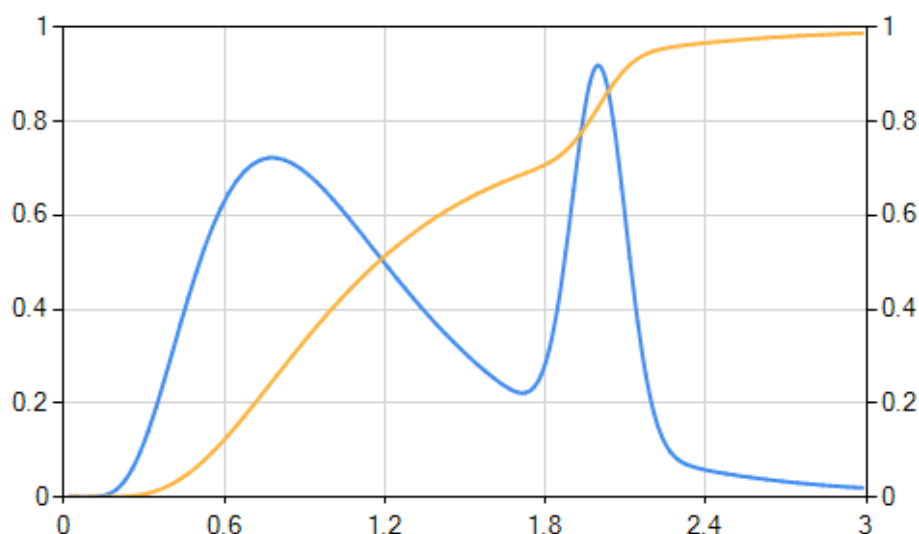


Figure 27 Assumed probability density function (blue) and cumulative distribution function leak flow rates in a particular statistically homogeneous set of leaks.

Using this distribution the uncertainties in the estimate of the leak flow rate (which is 1.31 kg/h) for various sample sizes as given in the table below.

#Samples	1	3	10	30
<Averages>	1.31	1.31	1.31	1.31
<Median>	1.17	1.28	1.30	1.30
<-5perc>	0.46	0.74	0.99	1.12
<+5perc>	2.20	1.95	1.65	1.50

Table 5 Estimates of the statistics for average leaks flow rate using #Samples, assuming the leaks flow rate distribution of Figure 27 and 1 000 000 trials.

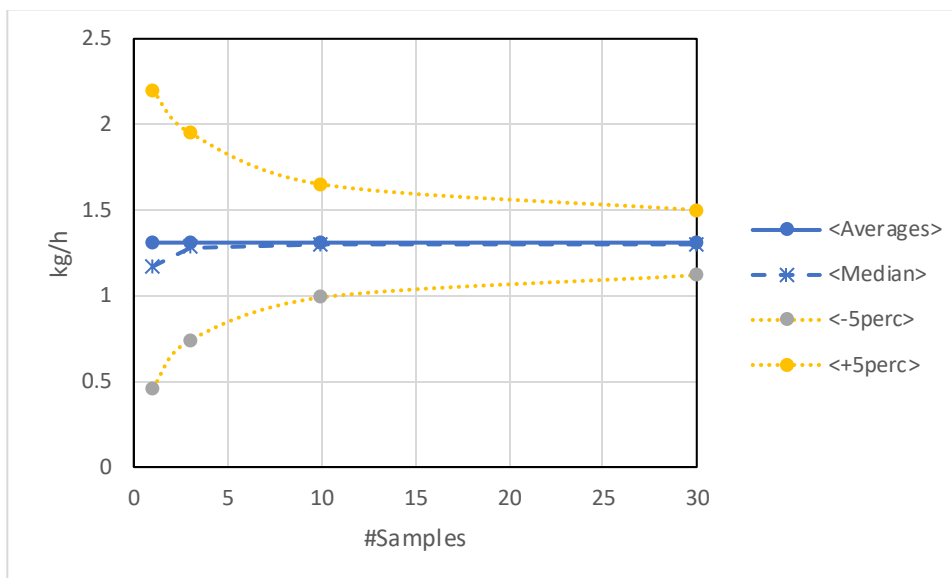


Figure 28 Statistics of the estimate of average leaks flow rate using #Samples, assuming the leak flow rate distribution of Figure 27.

The table and figure show that, with this assumed distribution, there are approximately 30 samples needed to obtain an estimate of the average leak flow rate with an uncertainty of about 20% and a confidence level of 90%. Because of the additional leak cause that introduces, on the average, larger leaks, obviously the average leak flow rate increases and also the estimate of the average leak flow rate increases. Also the uncertainty increases, compared to the previous example.

Cost benefit analysis.

There is as yet no direct financial incentive to report lower methane emission, so any financial cost benefit analysis is slightly arbitrary. However, here we sketch a possible quantified approach.

Assume:

- The cost per reported estimated emitted $\text{kg CO}_2\text{eq}$ is 0.02 €/kg.
- Estimation has to be reported with a 95percentile uncertainty interval.
- A single reference measurement costs 2000 €
- The leak emergence rate of a pipeline (of a given category) is 0.01 km/y
- The total length of that particular category pipeline is 5000 km.
- The occurring leak flow rates are distributed according Figure 27 and we may use figure 26 to assess the uncertainties that are due to the spread of the distribution and the uncertainty in the reference measurements
- A leak survey costs 50 €/km
- There is no explicit cost of lost methane

If 5 reference measurements are available, we have to base our reporting on the assumption that the average leak flow rate is 1.8 kg/h. If 10 reference measurement are available we are allowed to use a value of 1.6 kg/h.

If we perform a leak survey once every 5 yr, we expect to locate 250 leaks. We assume that we are allowed to calculate with 50% of that number as the average number of leaks present on average of the last 5 years. So we report 125 leaks

If we perform a leak survey once every 2 yr, we expect to locate 100 leaks. We assume that we are allowed to calculate with 50% of that number as the average number of leaks present average of the last 2 years. So we report 50 leaks.



A comparison of the costs of the 4 options (5 or 10 reference measurements, 2 or 5 year interval leak survey) is shown in the table below.

Option	Cost ref meas [€]	Cost survey [€/y]	Cost emission [€/y]	Payback time [yr]
5 ref meas + 5 yr interval	€ 10,000	€ 50,000	€ 39,420	
10 ref meas + 5 yr interval	€ 20,000	€ 50,000	€ 35,040	
Difference	€ 10,000	€ 0	-€ 4,380	2.28
5 ref meas + 2 yr interval	€ 10,000	€ 125,000	€ 15,768	
10 ref meas + 2 yr interval	€ 20,000	€ 125,000	€ 14,016	
Difference	€ 10,000	€ 0	-€ 1,752	5.71

Table 6 Calculate payback time for (additional) reference measurements

It is perhaps worth pointing out that leak repair costs are independent of which option is chosen. Leak emergence is always the same and each leak that occurs has to be repaired sooner or later.

Another observation is, that (when not calculating with NPV, net present value), any expenses in reference measurements are eventually profitable.

Finally, obviously, the payback time of any expenses for reference measurement is inverse proportional to the average flow rate of the leak and the number of leaks actually occurring.



IV. Proposed measurement protocol

Equipment.

The complete list of equipment needed for field measurements is:

1. Suction rod
2. Flexible tubing
3. Header with valves
4. Filter
5. Flow measurement device incl. read-out
6. Methane concentration monitor incl. read-out
7. Suction pump
8. Manometer (underpressure)

(Minimum) auxiliary equipment is:

- 1 Hammer
- 2 Measuring tape
- 3 Sample bags
- 4 Calibration gas (1% methane in dry air)
- 5 Calibration gas (10% methane in dry air)
- 6

Conditions

- The location of the leak (xy) must be known within reasonable tolerance (better than 0.3 m)
- The location of the leak (z) must be known with reasonable certainty to be between 0.3 and 1 m below surface
- The source of the leakage must be known beyond reasonable doubt to be a specific gas pipeline
- The soil must be sufficiently dry to avoid clogging of the suction tubes, tubing and filter
- The methane concentration of the gas in the pipeline must be known or determined

Procedure

Set up

1. Suction tubes
 - a. The suction tubes are pressed or hammered into the soil to a depth of 50 cm (see indicator ring around the tube)
 - b. The default pattern is shown in the figure below. The central tube is positioned on top of the leak

Note for Kiwa site: variations on the default pattern are part of the experiments

Note: If possible, check for the presence of gas in the soil at larger distance (2 – 5 m) around the leak location. If such gas is present, additional suction tubes at larger distances around the leak location are recommended for use in the initial phase of suction in order to reduce the time needed to reach a equilibrium between suction and leakage.

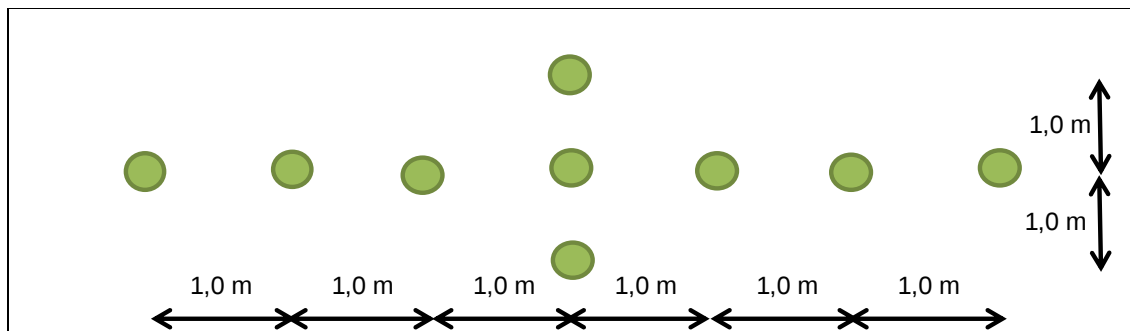


Figure 29 Schematic drawing of the pattern of suction locations. The central rod is located on top of the leak..

2. Header. All suction tubes are to be connected individually to the central header. Connect the header to the suction pump using a single line.
3. Suction pump. The suction pump has an input filter. Check for the presence of moisture in the filter and remove water and droplets before starting the pump (check again and remove any water direct after the measurements).
4. Flow meter. Connect the outlet of the suction pump to the inlet of the flow meter. Also connect the electronic control/read out-unit to the flow meter. The read-out is in m^3/h (air).
5. Gas concentration monitor. Use the side branch of the T-joint to connect the outlet of the flow meter to the inlet of the gas (methane) concentration monitor.
Note for Kiwa: The use mode of the Irwin Inficon gas concentration monitor is the setting "bovengronds lekzoeken".
6. Suction blow off. Connect the main branch of the T-joint to the blow off pipe.

Measurement process

1. Take a photo of the measurement site, showing the configuration of the suction tubes.
2. For this, the box containing the mass flow controllers need to be opened. Wear an operational personal methane detector when doing this.
For Kiwa site only: close the supply to the other leaks.
3. Disconnect the line between the suction pump and the flow meter and connect it to the blow-off. Start the pump and check during 5 minutes that no water collects in the lines between the suction rods and the pump and in the filter. If all remains dry then reconnect the line, otherwise postpone the measurement (and inform the project leader / customer)
4. Start the pump. Check all connections for (audible) suction of external air.
5. Check if data logging is operational (computer program running), and mark the start time in the report
6. Mark the flow and concentration every 15 minutes.
7. For Kiwa site only: close each of the valves of the suction tubes on the header one by one. If the total leak flow (concentration x flow) increases, keep the valve closed, otherwise reopen it. Do this until the flow becomes too small ($< 6 \text{ m}^3/\text{h}$).
Remark: the methane concentration will start to decrease. The reading of the Irwin methane meter is problematic. It will be 3 figures when below 1000 ppm. Above 1000 ppm it switches to a reading in percent, using a resolution of 0.1 %. This resolution is hardly sufficient to discern a decreasing trend.
8. Start doing, after three hours and if the gas concentration is between 0.1 and 0.9 vol%, the following actions every 15 minutes:
 - Register the values of flow and concentration at full suction capacity.
 - Throttle the flow using the slider on the header to $1 \text{ m}^3/\text{h}$ and wait 2 minutes
 - Register the flow and concentration in this situation.
 - Reopen the slider to nominal (full) suction capacity.



9. Terminate the measurement when over three consecutive readings (1/2 hour) show less than 5% relative decrease in methane suction flow.
10. Fill a sample bag directly after the last reading. Deliver the bag to the lab for analysis by GC.
11. Tidy up the site. Remove all plastic carpets on and around the leak site. .
12. For Kiwa site only: Reopen any closed other leaks (if relevant).
13. Store the measurement data on file/disk (and backup)

Additional notes for field situation³

1. It is assumed that the leak has previously been identified and located during the DSO's leak survey. Therefore typically some drilling holes are already in place for leaks in an urban environment (pavement, street, etc.). Also the DSO is responsible for providing barriers and warning signs to secure the measurement site.
2. At arrival at the site of the leak a quick leak survey is to be performed along the existing holes and in the area specified by the DSO with standard leak survey equipment (bell or carpet probe with semiconductor or FID concentration measurement) to make sure that there is (still) a leak indication on the surface (sometimes leaks cannot be found anymore, as a period of time has elapsed between the leak survey and the date of the measurement).
3. Concentration readings from the drilling holes via FID are then taken and documented. The pipeline documentation is checked for an understanding of the (supposed) location of the pipeline. Drilling holes are added to left and right of the pipeline (existing ones from locating tasks are usually only on top of the pipeline) to generate a symmetric field of probes. For this the holes with most significant concentrations are chosen as central area. It is checked that sufficient area is covered by using further holes in all directions to prove that at some distances no more (relevant) concentration can be found.
4. If the leak is located in the vicinity of a house service connection add probes in that direction, as it is typically unclear if the leak actually stems from the distribution line or service line. Drilling holes are usually in the depth of 30 – 50 cm, depending on the laying depth of the gas pipes and presence other infrastructure such as electricity cables, water pipes and fiber cables.
5. When placing the probes make sure to seal the annular gap between probe and hole as much as possible. According to German experience O-rings are suitable on concrete/pavement. If the leak is located below a grass/soil/field it is sufficient to just compact the excavated material from the drilling around the probe.
6. Document the starting concentrations of all probes before coupling the suction pumps (not the measurement case yet as parts of it are not EX-secure), then start the suction.
7. After a couple of minutes check all probes for underpressure and concentration individually using the "quick-release couplings on the top of the probes. Check for congestions if one or more probes don't show any underpressure. It may happen that the air flow resistance at some location is too high due to soil conditions (especially if very inhomogeneous soil is present, which is typical for old pipes buried after WW2) – then very little or no methane concentration will be observed for long time. In this case these probes can be relocated or removed as no leaking gas will escape via these paths.
8. From time to time the overall concentration in the accumulation hose is measured. When the concentration here is below 2.5 % the measurement logging is started and the measurement software will provide a timeline of methane leak rates to be used to check if the stable state has been reached.
9. Continue with the suction and periodical checking underpressure and concentration from the probes individually and deciding whether to remove

³ Derived from notes from Stefan Gollanek, describing German experience.



probes with none or very low concentrations while underpressure is available. Through this procedure the probing field around the actual centre of the leak can be decreased, as the original centre might well not be where the highest concentration has originally been observed! Also, by removing probes on the outskirts of the measurement field that show no more (or only marginal) concentrations most of our suction power is used for the area of soil that is still (partly) saturated by methane. Using an initially larger area speeds up the time it takes to create an area free of gas that has escaped the leak in the past around the actual leak⁴.

10. When the overall concentration measurement is stable for a longer period of time (this is not exactly defined, but the rate of concentration change should typically be pretty small for at least half an hour to an hour or so), check the surface within the measurement area for any gas concentrations via carpet/bell probe again. This proves that all the gas leaking from the pipe finds its way through the suction device and none escapes to the surface. If this check is ok, the actual measurement taken as the average value of concentration (and suction flow) over a period of roughly five minutes.
11. The typical volume flow during suction is about 20 m³/h and the FID is calibrated for 100 ppm of Methane, as this is the typical measurement range for leaks.

This completes the description of the German procedure. It is also recommended to check other details, depending on the situation (e.g. introduction of water to the air flow, weather conditions etc.). In their experience the reduction of gas concentration (gas suction rate) that is seen in the measurement equipment is very rarely “smooth” in time. Often step like changes are observed over time. It is also quite common, that in the beginning leak rates remain rather stable on a high level and only at some point rates start decreasing. It is speculated that this happens due to (sometimes extensive) “lakes” of natural gas forming right underneath the surface if it is mostly air tight, thus forcing the gas to creep along the sealed barrier. When the suction is started, this “lake” is emptied first and a rather continuous flow of natural gas is delivered to the probes from this reservoir.

Results and uncertainty

Results should be reported in kg_{CH4}/y (WG_ME, 2019) for each leak measurement separately.

Uncertainty should be explicitly stated and preferable based on 1 s (63% confidence interval).

Set-up

⁴ This is different from the protocol used in the suction experiments in this report.

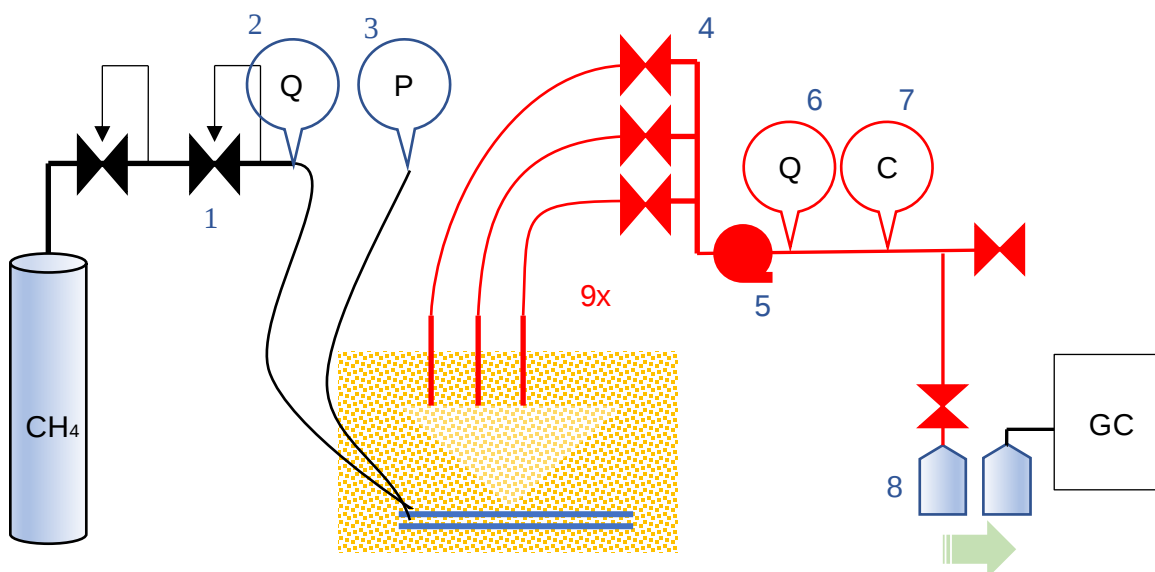


Figure 30 Layout of the installation and test equipment. Red parts are components of the suction measurement

- 1 pressure regulator (ca 100 mbar)
- 2 methane flow measurement
- 3 leak pressure measurement
- 4 manifold with valves
- 5 suction pump (ca 10 m³/h)
- 6 air methane mixture flow measurement
- 7 methane concentration measurement
- 8 sample bag for off line concentration measurement



V. Historic Dutch suction measurements dataset

Nr	Jaar	Materiaal	Drukklasse	Concentratie max. (ppm)	Lekgrootte (l/h)	Id	Comment
1	2005	PVC	100 mbar	150	11.2	2005-1	150 ppm
2	2005	Staal	8 bar	8000	65.7	2005-2	8000 ppm
3	2005	PVC	100 mbar	800	94.6	2005-3	800 ppm
4	2005	Staal	100 mbar	1000	14.9	2005-4	1000 ppm
5	2005	GGY	100 mbar	150	8.5	2005-5	150 ppm
6	2005	GGY	100 mbar	1000	4.6	2005-6	1000 ppm
7	2005	PVC	100 mbar	-	580.2	2005-7	- ppm
8	2005	PVC	100 mbar	-	1.6	2005-8	- ppm
9	2005	Staal	100 mbar	3000	32.1	2005-9	3000 ppm
10	2005	Staal	100 mbar	-	10.9	2005-10	- ppm
11	2005	Staal	8 bar	300000	460.9	2005-11	300000 ppm
12	2005	Staal	8 bar	400000	104.6	2005-12	400000 ppm
13	2005	Staal	4 bar	15000	58.4	2005-13	15000 ppm
14	2005	GGY	30 mbar	800	170	2005-14	800 ppm
15	2005	GGY	30 mbar	3000	15.9	2005-15	3000 ppm
16	2005	GGY	30 mbar	1000	169.3	2005-16	1000 ppm
17	2005	HPE	100 mbar	300	231.4	2005-17	300 ppm
18	2005	PE	4 bar	100	690.1	2005-18	100 ppm
19	2005	PE	4 bar	500	22.1	2005-19	500 ppm
20	2005	PE	4 bar	60	91.4	2005-20	60 ppm
21	2005	GGY	70 mbar	1000	46.1	2005-21	1000 ppm
22	2005	GGY	30 mbar	3000	350.2	2005-22	3000 ppm
23	2005	Nod. GY	30 mbar	800	230.5	2005-23	800 ppm
24	2005	Nod. GY	30 mbar	100	156.7	2005-24	100 ppm
25	2005	Nod. GY	30 mbar	800	96.1	2005-25	800 ppm
26	2006	GGY	30 mbar	1800	167	2006-26	1800 ppm
27	2006	GGY	30 mbar	740	10	2006-27	740 ppm
28	2006	GGY	30 mbar	350	18	2006-28	350 ppm
29	2006	GGY	30 mbar	780	9	2006-29	780 ppm
30	2006	GGY	30 mbar	130	452	2006-30	130 ppm
31	2006	GGY	30 mbar	370	48	2006-31	370 ppm
32	2006	GGY	30 mbar	5600	31	2006-32	5600 ppm
33	2006	GGY	30 mbar	180	15	2006-33	180 ppm
34	2006	GGY	30 mbar	6700	72	2006-34	6700 ppm
35	2006	GGY	30 mbar	240	7	2006-35	240 ppm
36	2006	GGY	100 mbar	2500	24	2006-36	2500 ppm
37	2006	GGY	100 mbar	10000	32	2006-37	10000 ppm
38	2006	GGY	100 mbar	1560	9	2006-38	1560 ppm
39	2006	GGY	100 mbar	1300	15	2006-39	1300 ppm
40	2006	GGY	100 mbar	1300	4.5	2006-40	1300 ppm
41	2006	GGY	100 mbar	1000	12	2006-41	1000 ppm
42	2006	GGY	100 mbar	15000	117	2006-42	15000 ppm
43	2006	GGY	100 mbar	15000	76	2006-43	15000 ppm
44	2006	GGY	100 mbar	460	4	2006-44	460 ppm
45	2006	Slagvast PVC	100 mbar	3400	13	2006-45	3400 ppm
46	2006	Slagvast PVC	100 mbar	150	6	2006-46	150 ppm
47	2006	Slagvast PVC	100 mbar	7700	35	2006-47	7700 ppm
48	2006	Slagvast PVC	100 mbar	9100	20	2006-48	9100 ppm
49	2006	Slagvast PVC	100 mbar	1220	3	2006-49	1220 ppm
50	2006	Slagvast PVC	100 mbar	700	10	2006-50	700 ppm
51	2014	AC	100mbar	114	80.6	2014-51	114 ppm
52	2014	AC	100mbar	170	203.9	2014-52	170 ppm
53	2014	PE	100mbar	50	98.5	2014-53	50 ppm
54	2014	AC	30mbar	150	205.1	2014-54	150 ppm
55	2014	Staal	8 bar	Tussen 600 en 700	2179.5	2014-55	Tussen 600 en 700 ppm
56	2014	PE	100 mbar	300	0.3	2014-56	300 ppm
57	2014	Staal	8 bar	100	0	2014-57	100 ppm
58	2014	Nod GY	8 bar	80	581	2014-58	80 ppm
59	2014	Nod GY (300mm)	1 bar	240000	31.1	2014-59	240000 ppm
60	2014	PE80	3 bar	800	24.9	2014-60	800 ppm
61	2014	PE100	8 bar	50	0	2014-61	50 ppm
62	2014	PE80	3 bar	44	9.4	2014-62	44 ppm
63	2014	Nod GY	1 bar	Tussen 150 en 250	0.2	2014-63	Tussen 150 en 250 ppm
64	2014	PE 63	3 bar	7000	48.8	2014-64	7000 ppm
65	2014	PE 80	4 bar	700	712.6	2014-65	700 ppm
66	2014	Staal	8 bar	1600	215.9	2014-66	1600 ppm
67	2014	Nod GY	4 bar	7000	6.1	2014-67	7000 ppm