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EVALUATION OF METHANE EMISSIONS FROM THE SPANISH GAS DISTRIBUTION SYSTEM

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ABSTRACT

This paper presents new results on the characterization of leak rates in gas distribution networks. The work was motivated by the need to update the emission factors used to estimate methane emissions in the Spanish network. The work included a survey of the values accepted in other countries as well as a detailed characterisation of the leak rates in polyethylene, medium-pressure B mains. The pressure variation method was selected for the field tests, which were fulfilled in 34 sites. The results obtained confirm that the leak calculation procedure used in Spain overestimates the amount of natural gas released to the atmosphere. Based on the results of this study, a new calculation methodology has been developed and submitted to the Spanish Ministry of Environment. On the other hand, the experimental data reported here are thought to be representative of PE-MPB lines in other countries, and might be useful to check existing leak calculation methods.

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1. INTRODUCTION

A small fraction of the natural gas fed into the distribution systems is lost through leakages in the network, and both the assessment and reduction of those losses are permanent objectives of the gas companies. The entering into force of the Kyoto protocol has motivated an increased attention to this issue. Although methane is emitted in much lower quantities than CO_2, its 21-fold higher 'global warming potential' brings it to the second place in the ranking of greenhouse gases. For example, EIA (2002) [1] estimated that methane contributed about 9% of the total emissions of greenhouse gases generated in USA in 2001.

In the European Union about 80% of the methane emitted to the atmosphere is attributed to natural gas released from the distribution systems [2]. According to [3], these losses include: the fugitive emissions (all small and more or less continuous leaks from the flanges, valves and equipments of the network), pneumatic emissions in valves and gas vented due to maintenance works or incidents. However, gas losses are not measured directly but are estimated according to the various methodologies available. Such estimates are known to involve large uncertainties and further work is needed to improve their reliability, both regarding global emissions as well as their distribution among the different countries. Besides their relevance for the evaluation and control of global climatic changes by national or international organizations, the knowledge of methane emissions in the natural gas distribution networks is important for the distributing companies, both for accounting purposes and for the search of solutions in order to gradually reduce the leakages.

The common practice is to estimate gas emissions in distribution networks using emission factors which express the volume of emitted gas by unit of length or by element [3]. Those factors are different for the various materials and work pressures, although the classification varies with the particular method. The calculation methods and their associated emission factors are different in the diverse countries, and their application to a particular network can yield a broad range of results. The selection of the most suitable procedure for a particular situation is not trivial, and ideally should be based on field data. However, such studies are very costly and only a few comprehensive works have been found in the technical literature reporting measurements of the volume of gas emitted in distribution networks. Therefore, the development of reliable procedures for the evaluation of methane emissions in a particular network is still an open issue needing further efforts, especially regarding field measurements.

In Spain, the gas companies submit every year a report to the Ministry of Environment with their estimations of methane emissions. The quantification is made using a suite of emission factors contained in a procedure elaborated by Gas Natural SDG a number of years ago [4]. However, it was suspected that the emission factors considered in this procedure are not representative of the present situation, due to the construction of many new pipelines and to the significant improvements made in the last years. Therefore, the emission factors probably had to be modified, which required a specific study including an adequate characterisation of the actual leak rates in the distribution network of Gas Natural SDG.

By the end of 2004, Gas Natural SDG in collaboration with Zaragoza University started a study aimed at updating the emission factors for the Spanish distribution network. In the first place, a survey of the methodologies currently used in other countries was completed, which evidenced large discrepancies between some of the emission factors used in Spain and the corresponding intervals for the ensemble of the other methodologies. The main goals of this work were:

- To identify the aspects of the methodology used by Gas Natural SDG requiring further study, according to its contribution to the total methane emission and to the magnitude of the differences with respect to other methodologies.
- To update the methodology for estimating emissions in the Gas Natural SDG's network, taking into account more recent studies and the emission factors accepted in other countries.
- To perform test campaigns designed to determine some selected emission factors in the Spanish gas distribution system.

The methane emissions determined by Gas Natural SDG's procedure [4] were compared with the results obtained by applying the methodologies used in United States [5], United Kingdom [6] and Germany [3], as well as those recommended by IGU [2] and IPCC [7]. Based on this analysis, the procedure was modified to calculate the emissions in service and distribution pipelines as a whole. Also, some of the emission factors were modified to approach the average emissions obtained with the procedures accepted in other countries. These are considered more reliable than the values proposed in Gas Natural SDG's procedure as they are supported by detailed field campaigns, while no such data are available in Spain. Also, some field tests were performed to characterize the parts of the network with the highest contributions to the total estimated emissions. The network of polyethylene at 0.4 - 4 bar (PE-MPB) was selected as the first candidate. The measurements performed demonstrated that the actual leak rates were significantly lower than those calculated with the emission factors proposed in the current procedure. As a result, a new procedure has been proposed and submitted to the Spanish administration for approval.

This paper summarises the main results obtained in the field tests on PE-MPB networks. Sections 2 and 3 describe the principles and practical application of the method used for the determination of leak rates. The results of the tests and their comparison with the current emission factors are discussed in Section 4.

2. MEASURING GAS LEAKAGE RATES IN DISTRIBUTION NETWORKS

2.1 Gas leakage test methods

A detailed analysis of the different testing methods was carried out in order to select the most suitable option for measuring the leakage in the particular conditions of Spanish medium pressure distribution networks. Several methods for measuring/estimating gas leakage rates in distribution networks were evaluated, with special attention to those used previously for field testing in different countries. Among the most relevant the following could be cited:

- Pressure Decay Method (PDM)
- Suction Method (SM)
- Bagging Method (BM)
- Pressure Variation Method (PVM)

The pressure decay method relies on measuring the decrease in pressure in an isolated section of pipeline over a determined period of time, for calculating the gas leakage flow rate. The PDM is considered one of the more reliable methods for estimating gas emissions, and has been extensively used by British Gas [6, 8, 9]. The main disadvantages refer to its application in practice, as it involves relatively high costs and requires cutting off the service to the customers connected to the test section.

In the suction method, probes are used to aspirate gas from the soil in the area surrounding a pipe leak, and the leak rate is calculated from the methane concentration in the gas sample [10]. The test procedure must be carefully designed to limit uncertainties due to the many sources of error inherent to the method. For the application of this method, the leaks must be previously located.

The bagging method consists in bagging the pipe in the leak zone, aspirating the gas from the bag and measuring the methane concentration and flow rate [11]. This method seems to be more reliable than the SM, but it has the same disadvantage in relation with the leak localization requirement.

The pressure variation method was the one selected for the field tests and is described in the next section. This method was considered to provide the best compromise between reliability and cost for the particular case of the Spanish network.

2.2 Pressure variation method

The pressure variation method is based on the principle according to which the leakage flow rates are proportional to the network pressure [12], whereas gas offtake by the customers remains constant when pipeline pressure is changed. So, by modifying the grid pressure it is possible to determine both the total leak rate and the customers flow from the change in the feed flow into the test section. Figure

1 illustrates this behaviour. Ideally, the flow rate would display a linear dependence with pressure, but actual values display some oscillation around a straight line. The basic steps required to characterise a section of the network are:

- Measurement of gas flow rate at different pressures about the operating point
- Estimation of consumption by users. This value is calculated as the intercept in the Y axis by extrapolation of measured values using a linear fit
- Estimation of leakage flow rate at normal work pressure, as the difference between the interpolated value for that pressure and the consumption by users.

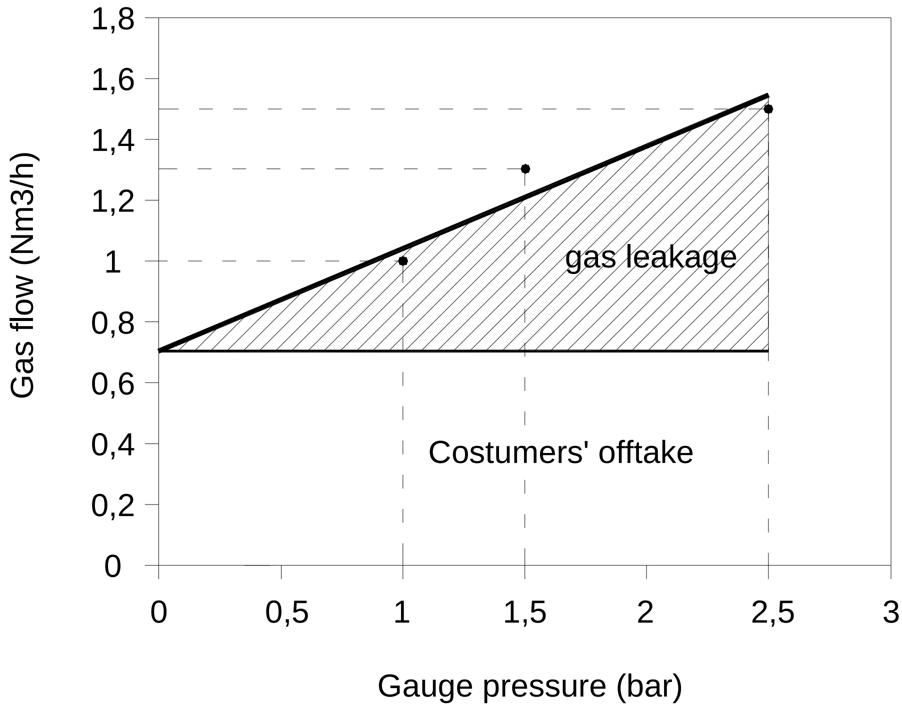

Figure 1: Principle of the pressure variation method

This procedure involves several sources of uncertainty, as described in a subsequent section. By far, the largest errors are those associated to the behaviour of consumers' offtake. In the first place, if it is much larger than the leakage rate, the inaccuracy of the flowmeter can become comparable or even exceed the magnitude of the estimated leakage flow rate. In the second place, an assumption inherent to the method is that gas consumption remains constant during the period of the test; if fluctuations are too large, the procedure depicted in Figure 1 cannot be applied and the results are useless. Therefore, the range of applicability of the PV method is restricted to networks with a feed flow that remains sufficiently low and stable during the test period. In fact, these constraints have prevented its application in countries where this cannot be guaranteed at any time along the year. This motivated Rhurgas to develop more sophisticated variants of the PV method [12], including cyclic variations of pressure in order to minimize the uncertainties due to fluctuations in users consumption, which still resulted in a broad dispersion of estimations about the mean due to this cause.

The pattern of consumption in countries of Southern Europe is, however, very different to those found in Germany or UK. Since the use of hot water reservoirs is not an extended practice, gas consumption was expected to be very low during warm nights in residential areas. The test campaigns were programmed in summer nights, typically between 23h and 5h. The results confirmed that almost two thirds of the selected sites were adequate for this method.

Therefore, the PV method was selected for this project as an optimal compromise between accuracy and cost/effort. Like the pressure decay method, it is a robust procedure and avoids the need to identify the leaks in advance as well as the risk of missing some of them. On the other hand, it shares with the SM or BM the advantage of not requiring stopping the service to customers.

Nevertheless, the test procedure had to be carefully designed to guarantee the validity of the results. The experiences reported by Rhurgas and Gaz de France [12, 13] and the studies accomplished by Gas Natural and LITEC [14] using this method in the Spanish medium pressure distribution network allowed detecting and solving several problems for the field campaign.

The linear proportion between leak rate and pipeline pressure in the medium pressure range (0.4-4*10^5 Pa) was checked, in order to assure the reliability of the PVM for field testing. The determination of the maximum constant customer offtake and its variation limits, which affect the accuracy in the estimation of leakage flow rate, was the other question solved. The expected range of leak rates for the sections of network to be tested was also determined. Those previous studies allowed designing the equipment for measuring leakage flow rates in medium pressure B polyethylene networks.

Special attention was dedicated to the reliability required for the instrumentation, mainly regarding the flowmeters, which had to enable a wide measuring range while keeping the high accuracy needed to resolve the small flow rates due to leakages. The solution was to install two flowmeters with different ranges (Table 1), mounted in parallel in a measuring unit specifically constructed for these tests (Figure 2). This unit also included the pressure and temperature transmitters needed to correct the measured flow rates. The outputs of all the instruments were continuously recorded during the test period using a PC with an analog-to-digital converter card, controlled with software specifically developed for this application.

The measuring unit was inserted in one of the two parallel lines of the Station for Metering and Regulating (SMR), by means of which the service pressure was varied in the range 0.4-4*10^5 Pa as required for the PVM.

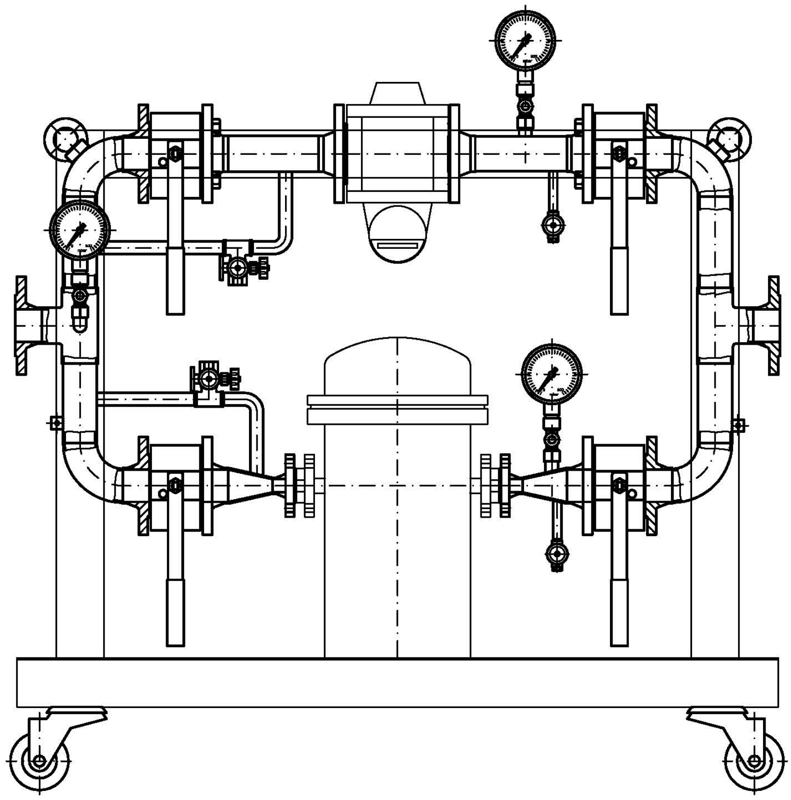

Figure 2: Measuring unit used for the pressure variation method

Instrument	Range	Frequency	Error
ELSTER G65-DN50 turbine flowmeter with ELSTER-EK230 electronic corrector	0.6 to 100 m^3/h	10 impulse/m^3	2% for range 0.6-10 m^3/h 1% for the rest
ELSTER G4 membrane flowmeter with ELSTER-EK230 electronic corrector	0.04 to 6 m^3/h	100 impulse/m^3	3% for range 0.04-0.6 m^3/h 2% for the rest

Table 1: Characteristics of the flowmeters

2.3 Campaign organization

Taking into account the estimations of annual emissions from the Gas Natural SDG's distribution network, as well as the contribution of the different pipeline materials and pressure ranges, it was decided to first evaluate the average emission factor for medium pressure B (MPB, $0.4\text{-}4 \cdot 10^5$ Pa) polyethylene distribution network.

The selection of the network sections to be tested was another demanding task in the preliminary works. Distribution network sections feeding mainly domestic customers were selected, so that low gas consumption could be guaranteed during the testing periods. Nevertheless, some industrial users were also included and it was necessary to ask for their collaboration in order to limit the gas demand during the measurements. All the possible independent network sections of medium pressure PE mains, with lengths from 1 to 70 km, were considered. Those with more stable and smaller customer offtake during summer nights were finally selected as testing sites. The tests were fulfilled in 34 network sections distributed over the whole country.

Two work groups were organized and trained for developing the field test campaign, and where in charge of the networks in the Southern and Northern regions of Spain, respectively. The measurements were performed during the nights in summer (typically, between 23h and 5h), when the consumption by the users was very low and enabled obtaining reliable results with this method. The tests were carried out during July, August and September of 2005.

2.4 Test procedure

The test procedure included three stages intrinsically linked: previous work, measuring sequence and data recording.

The main tasks in the previous work stage are to install the measuring equipment in the Station of Metering and Regulating and to verify the correct linked operation of the two systems. The most adequate flowmeter should be selected before passing to the measuring stage, using the one with the lowest range (G4) whenever it is possible.

Once the customer offtake reaches a stationary value the measuring sequence was initiated. The gas flow rate fed into the test section was determined for four different pressures with 0.5 bar intervals. After steady conditions were reached, data were recorded for 30 minutes at each pressure evaluated. The results were discarded if the gas flow rate displayed fluctuations or drifts during the test. The total test time was around 3 hours.

Data recording included not only the signals acquired by the computer (flow rates, pressure, temperature), but also all the operations, incidences and parameters measured in the SMR. The data files were sent to Zaragoza University once a week for subsequent processing.

3. DATA PROCESSING

The basic procedure for the estimation of leakage rates from the measurements at different pressures was already illustrated in Figure 1. Data processing includes also a data validation procedure, based on the magnitude of the standard deviation of flow rate series for each work pressure and on the evolution of the feed flow with pressure. In general, a test was considered not valid when any of the following situations were detected:

- The measured flows are greater than 100 Nm^3/h for at least three of the tested pressures.
- The fluctuation of measured flow reaches values close to the mean value.
- The variation of flow rate is inconsistent with the increase in pressure.

As a result, 13 out of 34 sites were discarded. In most cases, the cause of rejection was a too high feed flow.

The valid tests were processed to derive the emission factor representative of each of the 21 sites. Linear regression was used to find the straight line representing the influence of pressure on the total flow rate supplied to the test section. The customer offtake was estimated as the intercept with the Y-axis (zero gauge pressure) and the leak rate as the difference between the total feed flow for the work pressure of the network and the customer offtake (see Figure 1). The emission factors were determined by dividing leak rates (in Nm^3/h) by the length of the corresponding test section (in m), and then converting the result to Nm^3/year/m. The average emission factor was calculated as an average of the local emission factors, weighted with the length of the tested sections.

The various sources of error involved in the test and calculation procedures were considered carefully in order to assess the uncertainty in the emission factors obtained. The global uncertainty combines the error in the estimation of the local emission factor in the individual sections tested and the statistical error associated to the extrapolation to the whole network.

Local emission factors are calculated from:

- The total flow rate estimated at the operating pressure (Q_{pt})
- The customer offtake, taken as the flow rate extrapolated at zero gauge pressure (Q_o)
- The total length of the section.

The length is known with good accuracy and, therefore, the error associated to local emission factors (E_{EF}), are calculated from those for flow rates (E_{Qpt}, E_{Qo}) as:

$$E_{FE} = \sqrt{E_{Qpt}^2 + E_{Qo}^2}$$

The values for Q_{pt} and Q_o are affected, in the first place, by instrumental errors (flow rate, pressure…) and, in the second place, by the uncertainties associated to interpolation and extrapolation using a linear fitting. Both aspects are included in the following expression (e.g., see [15]):

$$E_Q^2 = \sigma_{a1}^2 + \sigma_{a2}^2 \cdot p^2 + 2 \cdot \sigma_{a1a2}^2 \cdot p$$

where p is taken as the network work pressure for determining the error of total flow rate at that pressure (E_{Qpt}) and is equal to 0 for determining the error in the flow rate of costumers' offtake (E_{Qo}). On the other hand, σ_{a1}, σ_{a2}, and σ_{a1a2} are the uncertainties for the *a1* coefficient (intercept in the linear fit), for the slope (*a2*) and for the covariance, respectively. The parameters σ are calculated from the technical specifications of the instruments and from the standard deviation of the flow rates at each tested pressure.

The statistical error due to the extrapolation to the whole network was estimated using the Student t-test, which takes into account the variability of local emission factors between different locations.

4. EMISSION FACTOR FOR MPB POLYETHYLENE NETWORKS

Figure 3 represents the histogram and accumulated distribution of the emission factors obtained in the 24 sites with valid results. No leak was detected in four of the sites (19%); the rest of the cases display monotonic decrease in frequency as the emission factor increases. The numerical values are shown in Table 2, sorted in descending order of emission factor.

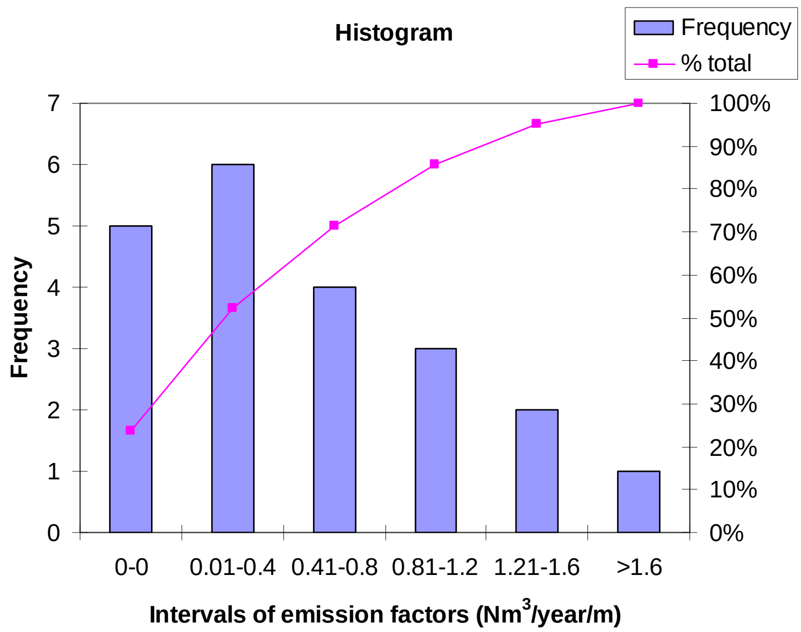

Figure 3: Histogram of the emission factors

SMRs	**L** (m)	**Pg** (bar)	***Q_{leakage}*** (Nm³/h)	***Emission factor*** (Nm³/year/m)	***Error*** (Nm³/year/m)
Morón de la Frontera	2005.9	1.0	0.4659	2.03	±0.19
Seseña Nuevo	12091.0	2.0	2.1263	1.54	±0.03
La Vereda	9127.1	1.0	1.3408	1.29	±0.11
S. A. de Benajeber I	16690.1	1.5	2.2731	1.19	±0.03
Ocaña	21542.3	2.0	2.7430	1.12	±0.02
Galapagar	9691.0	2.0	1.0718	0.97	±0.02
Renedo	7126.3	2.0	0.4216	0.52	±0.06
Illescas	29936.7	2.0	1.7048	0.50	±0.15
Seseña Viejo	37041.1	2.0	1.9276	0.46	±0.08
Cangas	24074.0	1.0	1.2483	0.45	±0.01
Penilla-Sarón	11989.1	2.0	0.4308	0.31	±0.04
Granja García	7019.7	2.0	0.1964	0.25	±0.01
Rinconada	9064.4	1.5	0.2465	0.24	±0.12
Ontígola	25543.4	2.0	0.5592	0.19	±0.00
Azucaica	3706.2	2.0	0.0656	0.16	±0.05
Puerto Sagunto	63108.6	3.0	0.5844	0.08	±0.01
Villalba	16471.0	1.0	0.0000	0.00	0.00
Carteros	1943.7	4.0	0.0000	0.00	0.00
Cortes	11424.6	2.0	0.0000	0.00	0.00
Fitero	6835.7	2.0	0.0000	0.00	0.00
Funes	6547.4	2.0	0.0000	0.00	0.00

Table 2: Local emission factors

The average emission factor obtained for medium pressure B polyethylene lines was 0.46 Nm^3/year/m. The associated uncertainty was ±0.14 Nm^3/year/m (30.08%), for 70% confidence level; that is, there is a probability of 70% that the actual emission factor is between 0.32 and 0.60 Nm^3/year/m. For a confidence level of 90%, the uncertainty band is ±0.22 Nm^3/year/m.

The analysis of errors indicated that the largest contribution to the global uncertainty comes from the extrapolation of results from the sample sites to the whole network, while the errors in the estimation of local emission factors display a lower influence. Therefore, it can be concluded that the test method is considered reliable enough for this application, and that the uncertainty band might easily be reduced by increasing the number of sample sites.

The methodology accepted in Spain for the estimation of methane losses considered an emission factor for MPB-PE lines of 1 Nm^3/year/m. However, the tests provided an average value of 0.46 Nm^3/year/m and demonstrated that such factor is below 0.68 Nm^3/year/m with a 95% probability. This methodology needed, therefore, to be updated. Also, the values proposed by other methodologies for this type of lines were considered as a reference. As shown in Table 3, emission factors available span over a wide range (0.06-1.10), with a mean value of 0.55 Nm^3/year/m. The emission factor currently used in Spain (1.00 Nm^3/year/m) is much higher than those values and than the factors obtained in UK or Germany, whose distribution networks are comparable to the Spanish case. Therefore, both the field tests and the situations in other countries indicate that the methane losses in Spain from MPB PE lines are clearly overestimated with the current methodology.

On the contrary, the average emission factor obtained from field tests (0.46 Nm^3/year/m) is perfectly consistent with the values accepted in other countries, being almost identical to the factor proposed by Eurogas-Marcogaz [3], which is a relevant reference for European countries.

Methodology	**Source**	**FE (Nm^3/year/m)**
E-M	Eurogas-Marcogaz [3]	0.47
IPCC	IPCC [7]	1.10
IGU	IGU [2]	1.00
Fraunhofer	Eurogas-Marcogaz [3]	0.33
Lott	Lott [5]	0.06
BG	Rose [6]	0.38
Average	Average from the preceding methodologies	0.55
Spain: PGM	Gas Natural SDG [4]	1.00
Spain: Measured	2005 Spanish campaign average	0.46

Table 3: Emission factors for MPB PE mains.

The modification of this emission factor leads, therefore, to a reduction of 54% in the estimation methane emissions from polyethylene MP-B mains. Other parts of the calculation procedure were also revised; in particular, the emission factor for steel pipelines was clearly too high compared with the values accepted in other European countries.

The application of the new procedure to the Gas Natural SDG network in 2004 year reduced the estimations of total gas emission from 0.905 (estimated with the previous procedure) to 0.645 tCH_4/km. Also the contribution of the different materials and pressures is significantly modified (Figure 4). The most important variation is observed for high pressure steel lines (HP S), which changes their contribution to the total emission from 54% with the old procedure to 21% with the new one.

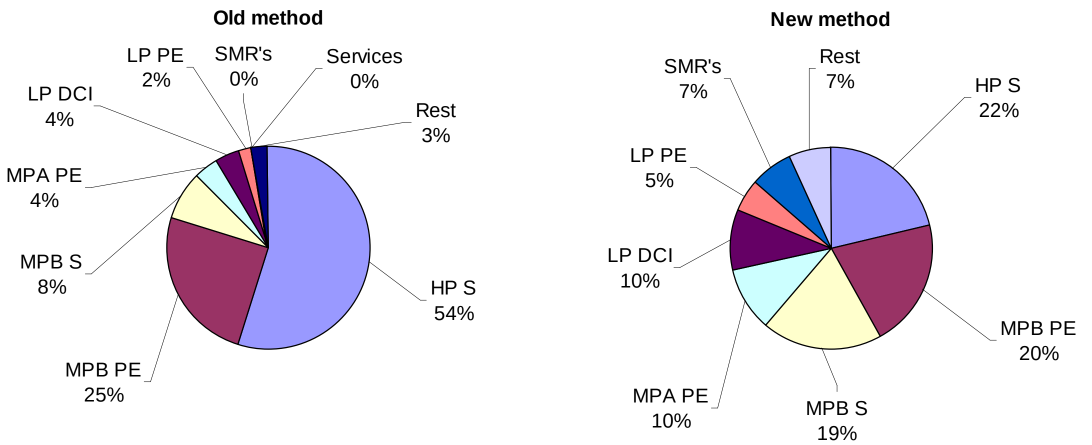

Figure 4: Change in the relative contribution to the total gas emission from old to new procedure

5. CONCLUSIONS

The pressure variation method has been applied for the determination of leak rates in the polyethylene, medium-pressure B mains of the Spanish network. Differently to other countries, the low gas demand in certain periods (summer nights) enabled obtaining reliable results with this procedure. Moreover, if consumer offtake is sufficiently low, the pressure variation method could be considered as the best compromise between accuracy and cost/effort among the methods available for the determination of leak rates. For the work reported, 21 out of 34 sites tested provided valid results for the characterisation of PE-MPB lines.

As a result, a new set of experimental measurements has been generated, which can be added to the scarce field campaigns reported worldwide. The results obtained for the PE-MPB network should be applicable to this type of lines in other countries having distribution networks with an age and maintenance routines similar to the Spanish case.

The experimental results confirmed that some of the emission factors included in the leak calculation procedure currently applied in Spain are overestimated. Namely, the emission factor for PE-MPB should be reduced from the present value of 1 Nm^3/year/m to 0.46 Nm^3/year/m, as derived from the field results. The new value is comparable to those accepted in other European countries, and almost identical to the emission factor proposed by Eurogas-Marcogaz. The factors for other types of lines (in particular, for steel) were also revised, and a new procedure has been submitted to the Spanish Ministry of Environment. The modifications proposed would reduce the estimated gas emissions in Spain for 2004 from 0.905 to 0.645 tCH_4/km.

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7. LIST TABLES

8. LIST OF FIGURES