



Metrological support for LNG and LBG as transport fuel

EMPIR Grant Agreement number	16ENG09
Project short name	LNG III
Project duration	2017-06-01 to 2020-06-30
Deliverable reference	D8
Deliverable title	Good practice guide for filter weighing and sampling particulates at LNG/LBG refuelling stations based on an assessment of the source, content, and potential impact of particles, particularly in LBG fuels
Involved partners (Lead partner in bold)	NPL , VSL
Due date of the deliverable	31/05/20
Actual submission date of the deliverable	01/06/20

Good practice guide for filter weighing and sampling particulates at LNG/LBG refuelling stations based on an assessment of the source, content, and potential impact of particles, particularly in LBG fuels

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Contents

Metrological support for LNG and LBG as transport fuel	1
1 - Introduction	3
1.1 Task objectives under LNG III	3
1.2 Scope of the Good Practice Guide	3
1.3 Particulate contamination causes and issues	4
2 – Filter weighing procedure	5
2.1 Considerations	5
2.2 Equipment	5
2.2.1 Autohandler	5
2.2.2 Balance	6
2.2.3 Temperature and Humidity Controlled Chamber	7
2.2.4 Filters	8
2.3 Filter weighing procedure	9
2.4 Calculations	11
2.5 Quality Assurance and Quality Control	12
2.6 Uncertainty	12
3 – Filter sampling method validation and determination of losses	16
3.1 Handling and transport of filters	16
3.2 Blanks	16
3.3 Setup of testing for particle loss through a sampling system	16
3.3.1 Generation of particle laden LNG in the laboratory	17
3.3.2 Determination of particulate losses through a sampling system	18
3.3.3 Validating the OPC against other particle sizing instruments and known PSL sizes	19
3.3.4 Test OPC with High Pressures and PSL	20
3.3.5 OPC and Filter mass equivalence	20
3.3.6 Build a sampling system testing rig	21
3.4 Determination of losses from a sampling system	22
4 – Conclusions	23
5 – References	24

1 - Introduction

1.1 Task objectives under LNG III

The aim of this task is to assess the source, content and potential impact of particles, particularly in LBG. To do this, a new method will be developed to traceably determine the mass concentration of particles on a filter collected in an LNG/LBG stream. The effect of conditions at refueling stations during filter preparations will be examined and NPL will test the loss of particulates through a standard pressure regulator. Based on the results a good practice guide for filter weighing and sampling particulates at LNG/LBG refueling stations will be written.

1.2 Scope of the Good Practice Guide

Liquefied Natural Gas (LNG) is natural gas that has been cooled and liquefied. This gives access to the use of natural gas in countries that have poorly developed gas pipelines and simplifies the logistics of supplying this fuel. LNG powered vehicles are seen across the World in Europe, Asia and the United States [1]. Particulate contamination is found in LNG and introduced through natural minerals or transportation and storage equipment [2]. These particles can be destructive to engines [2] so efforts must be made to monitor, fully characterize and ultimately eliminate them. A traceable, reliable and repeatable method for the determination of the mass concentration of the particulates in a volume of gas is required. Filters have long been used to collect and measure particulate matter in the area of ambient air monitoring and can, therefore, be considered as a reliable method to measure the particulate matter in a gaseous medium. This Good Practice Guide is intended to be used as helpful document for those wishing to set up their own measurement system for the determination of particulates in LNG. This guide will highlight the considerations, quality control and procedures required for weighing LNG particulates from a filter weighing methodology. It will also describe a method for the accurate measurement of the collected particulate mass on filters traditionally used for ambient air monitoring. It meets the requirements for filter storage; conditioning and weighing that are laid out in EN 12341:2014 [3]. Further to this it will offer guidance on the determination of particulate losses within sampling systems used at LNG refuelling stations.

Due to Covid-19 and the subsequent laboratory closures it was not possible to generate experimental results for the procedures recorded in this document. Therefore, although these procedures have been assessed for proof of concept, a full validation on real World LNG samples has not been possible. Although the original task asked for a list of recommendations from this document, I feel that this would be an oversimplification. This Good Practice Guide has instead highlighted many of the issues and pitfalls associated with setting up traceable measurement, from onsite sampling to the final mass value for particulates in LNG/LBG.

1.3 Particulate contamination causes and issues

Particulate contamination of liquified natural gas (LNG) and biogas (LBG) fuels can have severe consequences if not removed prior to use. Previous studies have shown that particles present in LNG can be naturally occurring, such as silicon dioxide (SiO_2), or can be present due to mechanical processes occurring in storage or during transport, for example metallic particles resulting from corrosion [2]. LBG can also be contaminated with silicon based particles, among other things, but it has been observed that particles are only present in trace amounts [4]. The levels of impurities in LBG is dependent on the initial biogas production method [5].

The presence of hydrogen sulfide (H_2S) in LNG and LBG can lead to the formation of metallic particles through the corrosion of containment vessels and engine components [6]. Sulfur containing compounds are among the most common contaminants of natural gas, originating from the material used to produce the gas. These compounds can corrode the pipes, containers and any other surface they come into contact with, producing particles in the liquid stream [7].

The contamination of LNG and LBG with siloxane can have many consequences for the combustion system. Silicon particles can potentially form in the liquid stream through the thermal decomposition of siloxane impurities present in the fuel [4]. Siloxanes are present in biogas as they are added to many everyday products such as cosmetics, textiles and lubricants [8]. The silicon side products of combustion can potentially aggregate on surfaces inside the engine or fuel cell and cause deterioration of engine components. These silicates can also cause a degradation of the catalytic converters on engine outlets and pose a hazard to human health if emitted [8], [9].

In order to minimize the concentrations of particulates in LNG and LBG samples, extreme care should be taken to remove any potential sources during production. Caution should also be taken to not introduce any additional potential particle sources during transport and utilization of the fuels. For example, the use of silicone containing lubricants while handling the fuel should be avoided. The potential impacts of these particles in the fuel are wide ranging, from the degradation of the engine components, which could result in reduced engine efficiency and operational costs, to potential environmental and health impacts as a result of poor engine performance and particle emissions.

2 – Filter weighing procedure

2.1 Considerations

These considerations originate from NPL's process in creating a weighing system and procedure in accordance with the standard EN12341:2014.

- All filters are weighed on high-accuracy single-pan balances in a temperature and relative humidity-controlled environment.
- The range of application for this procedure is from 25 µg to 8 mg of collected particulate, which represents measured concentrations in the order of 1 µg.m⁻³ dependent on exposure time and flow rate.
- The absolute combined filter and particulate mass must not exceed 300 mg. The procedure is suitable for the weighing of filters of any material, with diameters of either 37 mm or 47 mm. The procedure has been developed at NPL using a single pan balance, Mettler XP2U (0.1 µg resolution). This balance is calibrated by NPL's mass section on an annual basis. The resolution may be 0.1 µg but the uncertainty on a single weighing is a lot higher as expressed in the uncertainty budget.
- To prevent the loss of volatile and semi-volatile species, all sampled filters shall be stored at a temperature of ≤23 °C, in accordance with EN12341:2014.
- Static electrical charge is known to have a potentially significant effect on the weighing of filters, especially those made of PTFE. Trials have shown that the use of the Faraday cage weighing pan reduces this effect to within allowable tolerances. If this were not the case it would be apparent from repeat weighings and a failure to reach a stable weight. The standard weighing pan has shown to be acceptable for Emfab and glass fibre filters.

2.2 Equipment

The equipment used in this practice are as follows:

2.2.1 Autohandler

The design of the autohandler allows for the circulation of air around the top and bottom surfaces for all artefacts to be weighed, ensuring that they are fully conditioned at the desired temperature and humidity. Sample filters, calibration weights and quality control filters are delivered from their storage positions to the balance via a barcode reader for artefact identification. The autohandler should be serviced on a regular basis to ensure that performance is not compromised. This service interval will depend on usage, but will be annually during typical regular use.



Figure 1: Autohandler used for filter weighing at NPL

2.2.2 Balance

A balance with a resolution of $0.1 \mu\text{g}$ should be used (e.g. Mettler Toledo XP2U) and a MTL designed Faraday cage style weighing pan can be used to reduce the effects of static charges. Effect of static is negligible for Emfab filters but needs to be taken into account for PTFE/PFA filters and to a lesser extent quartz filters.

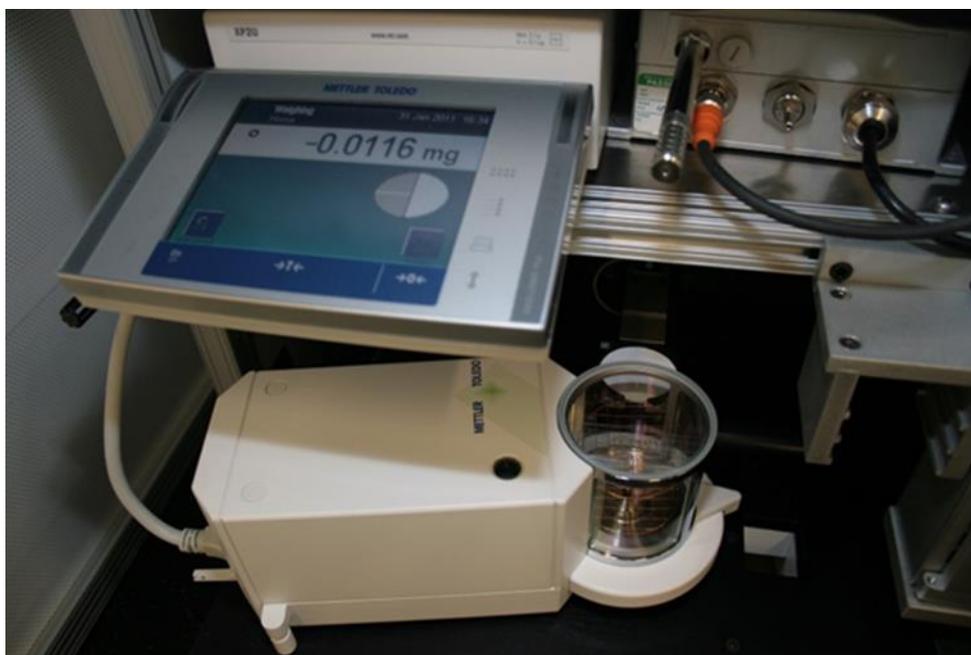


Figure 2: Mettler Toledo XP2U, balance used for filter weighing at NPL [10]

2.2.3 Temperature and Humidity Controlled Chamber

A climate-controlled chamber encloses the autohandler and shall be used for conditioning and weighing the filters. The temperature and the relative humidity shall be continuously monitored and controlled to $20\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ and $47.5\% \pm 2.5\% \text{ RH}$ respectively, measured as an hourly mean value. A temperature and humidity logger is used to record these conditions during filter conditioning and weighing.

The interior of the chamber shall be cleaned after a break in regular use and quarterly during regular use to remove the build-up of waste particulate matter within the chamber. The chamber should be serviced annually during regular use to ensure that the temperature and humidity control is not compromised.



Figure 3: Chamber used for filter weighing at NPL

2.2.4 Filters

This procedure covers the weighing of filters made from the following materials: quartz, glass fibre, PTFE and PTFE coated glass fibre. Filter diameters can be either 37 mm or 47 mm. Other filter diameters can be weighed if suitable filter holders are used. Other filter sizes are not covered by the procedure of the next paragraph.



Figure 4: (left) PTFE filters in their packaging case and (right) quartz filters [11]

2.3 Filter weighing procedure

The weighing procedure here is designed to mitigate both long- and short-term drift in the balance being used. To this end both weights internal and external to the balance are used. Traceability to the SI is assured through an annual calibration in the NPL Mass and Measurement area. The procedure for this annual calibration is not included here.

All weighings on the system are performed according to the following protocol:

1. Zero balance
2. Record empty pan weight, E_n
3. Place artefact (A) to be weighed on the balance pan
4. Record artefact weight, A_n
5. Remove artefact from balance pan
6. Record empty pan weight, E_{n+1}

Steps 2 to 6 can be repeated as many times as required to reduce the uncertainty in the measured weight of the artefact.

The weight of A is calculated from Equation 1:

$$A = \frac{\sum_1^n \left(A_n - \left(\frac{E_n + E_{n+1}}{2} \right) \right)}{n}$$

Equation 1

where:

- A = weight of artefact in mg
- A_n = weight of artefact at the nth weighing in mg
- E_n = empty pan weight before the A_n weighing in mg
- E_{n+1} = empty pan weight before the A_{n+1} weighing in mg
- n = number of weighings

For test weights $n = 1$, and for test filters and reference filters $n = 3$.

The first step of any weighing procedure is to warm up the balance to prepare the balance for weighing. This is achieved by weighing the 100 mg test weight 10 times.

After the balance has been warmed up, and every four hours, the following quality assurance protocol is run using the internal masses within the balance and two external test weights.

1. Weigh 100 mg test weight
2. Perform internal balance calibration
3. Weigh 100 mg test weight
4. Weigh 200 mg test weight

Two reference filters of the same material as the test filters are weighed at the beginning of the weighing procedure. These reference filters are always kept within the climate control chamber and are used as an indication of the system performance. The difference between the weights of the check filter between weighing sessions shall not exceed the 40 µg for unsampled filters and 60 µg for sampled filters, criteria for weight difference for filter weights. These requirements come from EN12341, gravimetric PM sampling.

2.4 Calculations

The unloaded or loaded filter weights are calculated according to Equation 2

$$m_{\text{unloaded}} \text{ or } m_{\text{loaded}} = \frac{(m_{t=0} + m_{t+24hr})}{2}$$

Equation 2

where:

m_{unloaded}	=	mass of unloaded filter (unsampled), μg
m_{loaded}	=	mass of particulate loaded filter (sampled), μg
$m_{t=0}$	=	mass measurement performed after 48 hrs of conditioning, μg
$m_{t=24}$	=	mass measurement performed after an additional 24 hrs of conditioning, μg

The collected mass on a filter is calculated according to Equation 3:

$$\text{Collected Mass} = m_{\text{loaded}} - m_{\text{unloaded}}$$

Equation 3

where:

Collected Mass	=	mass of particulate matter collected on the filter, μg .
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NPL weigh each filter 3 times each weighing session.

The particulate mass concentration is calculated according to the Equation 4:

$$\text{Particulate concentration} = \frac{\text{Collected Mass}}{\text{Sample Volume}}$$

Equation 4

where:

$\text{Particulate Concentration}$	=	concentration of particles in a gas sampled, $\mu\text{g}\cdot\text{m}^{-3}$
Sample Volume	=	volume of gas sampled by the filter, m^3

2.5 Quality Assurance and Quality Control

- If the two weighings of an unsampled filter differ by more than 40 µg then that particular filter should be discarded.
- Unloaded filters may be stored for up to 2 months before sampling.
- If the two weighings of a sampled filter differ by more than 60 µg then the result for that particular filter will be considered invalid.
- Sampled filters will be stored at a temperature of ≤23 °C before they are conditioned for weighing. After weighing the filters will be left in the autohandler until it is confirmed that the results meet difference in mass criteria over a 24 hour period stated in EN12341 (40 µg and 60 µg for unsampled and sampled filters respectively) and then stored in an air-conditioned laboratory.
- The maximum allowable change in humidity during conditioning and weighing is 5% Rh, as stated in EN12341.

2.6 Uncertainty

The model equation, which represents the procedure for obtaining the desired output quantity from the input quantities, is shown in Equation 5:

$$PM = m_{loaded} - m_{unloaded}$$

Equation 5

where:

PM	=	Particulate mass collected on the filter
m_{loaded}	=	Mass of the filter after sampling
$m_{unloaded}$	=	Mass on the filter before sampling

It is possible to introduce significant errors in the weight of collected particulate matter because of the loss of filter or particulate material during handling and transport, or the addition of matter not collected during sampling. The procedures for handling, storage and transport are designed to control these factors. The uncertainty of this measurement is not included in the uncertainty budget below.

The individual sources of uncertainty are summarised in Table 1.

Table 1: Table outlining the contributions towards the uncertainty budget and brief explanations on why these must be considered.

Contribution	Symbol	Maximum allowable uncertainty Component, μg	Why this needs to be considered
Mass $m_{\text{loaded}} - m_{\text{unloaded}}$	u_m		
Loss of semi-volatiles	u_{msv}	Zero by convention	<p>(Zero by convention)</p> <p>It is known that substantial fractions of particulate mass can be composed of semi-volatile components, which can volatilise at any time between entry to the sample inlet and weighing of the loaded filter, at a rate predominantly determined by the temperature of the sampling system and the filter. Hence, some loss of semi-volatile material is expected when this procedure is followed and the loss may differ between the different location, day and PM values.</p> <p>This volatilisation loss is limited within the standard measurement method laid out in EN12341:2014, by the constraints on the sampling system components and on sample storage, transport and conditioning. However, the definition of PM for the purpose of EN12341:2014 incorporates these losses of semi-volatile material. Therefore, the average effect of volatilisation losses on the measurement of PM is considered to be zero by convention, when the constraints set out in EN12341:2014 and this procedure are followed.</p> <p>EN12341:2014 specifies sampling should occur within 56 days of the pre-sampling weighing. If the same time period is used for the maximum period between sampling and post weighing then the maximum period between pre and post weighings is 4 months (112 days). If this time period is exceeded, then the mass measurement would not comply with EN12341 and would not be valid.</p>
Effect of humidity on filter	u_{mhf}	$\frac{40}{\sqrt{3}}$	<p>Extensive work on the effect of humidity on filter weight has been performed using the autohandler and conditioning chamber. This validation work on EN12341:2014 is summarised in Annex F of the standard. The humidity weight dependence of Emfab filters was found to be $0.7 \mu\text{g}.\% \text{Rh}^{-1}$ and the humidity weight dependence of quartz QMA filters</p>

			to be 2.8 $\mu\text{g}\cdot\% \text{Rh}^{-1}$. The range of allowable conditioning humidity is 5% Rh, so the maximum expected filter weight change between pre and post sampling would be 3.5 μg for Emfab filters and 14 μg for quartz QMA filters. In reality, due to the tight relative humidity and temperature control of the climate chamber ($20\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$ and $47.5\% \pm 2.5\% \text{RH}$), this dependence, u_{mhf} , is less than 7 μg for quartz QMA filters and less than 1.8 μg for Emfab filters.
Effect of filter drift	u_{mfd}	$\frac{135}{\sqrt{3}}$	Both Emfab and Quartz QMA filters slowly drift in weight over prolonged periods of time when conditioned at stable temperatures and humidities. This is mainly due to the manufacturing conditions being different from the conditioning conditions. Previous work has shown that Emfab filters always gain weight over time at a rate of 0.3 μg per day. While quartz QMA sometimes gain or sometimes lose weight over time, tests have shown a typical drift in quartz QMA filter weight of 1.2 μg per day.
Effect of humidity on particulate	u_{mhp}	$\frac{46}{\sqrt{3}}$	The effect of this on the uncertainty of the measurement is quantified by the constraint on mass change at the separate weighings of loaded filters given above (60 μg). From tests on the effect of humidity on particulate mass and the maximum allowable change in humidity of 5% Rh, the maximum change in particulate mass between the two weighings 24 hours apart is in the order of 46 μg . In reality due to the tight relative humidity and temperature control of the climate chamber ($20\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$ and $47.5\% \pm 2.5\% \text{RH}$), this dependence is less than 10 μg .
Buoyancy	u_{mb}	$\frac{3}{\sqrt{3}}$	The density of the surrounding air, which causes a buoyancy effect on the weight of the filters, is predominantly determined by the air pressure and temperature. Of these only the temperature is controlled as part of the filter condition requirements. However, the expected effects of buoyancy changes can be calculated from physical principles.
Static	u_{ms}	Negligible	(negligible) Static electrical charge is known to have a potentially significant effect on the weighing of filters, especially those made of PTFE. However, the

			use of the MTL Faraday cage style weighing pan is considered to control this and the associated uncertainty is considered to be negligible. For Emfab and quartz filters the standard balance pan is considered to deliver negligible uncertainty for the effect of static electrical charge.
Balance calibration	u_{mc}	2.7	Yearly calibration of balances is suggested
Balance linearity	u_{mbl}	1	(negligible compared to the mass of particulates on loaded filter)
Balance span drift	u_{mbds}	1	An internal balance recalibration every 4 hours removes the effect of span drift. An external independent weighing a 100 mg weight before and after recalibration is used to monitor the effect of the internal recalibration. The effect of internal recalibration and span drift over 4 hours must be less than 1 μ g in both cases. Span drift is also monitored by weighing a 200 mg weight in the 4 hourly QA procedure.
Balance zero drift	u_{mbdz}	Negligible	(negligible) Zero drift is controlled by zeroing the balance before an artefact is weighed.
Balance repeatability	u_{mbr}	$\frac{1.0}{t_{(n=8)}}$	(negligible compared to the mass of particulates on loaded filter)
Combined standard uncertainty	u_m	85.6	

3 – Filter sampling method validation and determination of losses

3.1 Handling and transport of filters

When handling filters and filter holders, clean tweezers and gloves must be used to prevent grease and other contaminants being introduced to the filters. Following the guidelines in EN 12341:2014, weighing room conditions must be recorded at every weighing session. If any visual defects are observed on a filter it is immediately disposed of. The guidelines outline that blank filters should be loaded into filter holders in a ‘clean environment’^[3], however, repeated 1 hour exposures on a forecourt, yielded mass concentrations within the uncertainty of the measurement (less than 17 µg) and so this contribution to any filter mass can be considered negligible. Therefore, clean room conditions are generally not necessary for standard forecourt filter loading into filter holders for measuring. While being stored or during transport, the filters must be placed within filter sealed containers that prevent exposure. Insulation, such as basic cool boxes, should be used to aid in maintaining a temperature ≤ 23 °C during transport.

3.2 Blanks

Blanks are the simplest method to assess the quality of results and to account for factors outside of our control. For each stage of filter preparation, handling and measurement, a blank should be used.

Two types of blanks are covered within EN 12341:2014:

Weighing room blanks – weights must be recorded at each weighing session alongside the sample filters. This ensures constant conditions within the weighing room.

Field blanks – These should be conditioned with the sample filters and weighed before transport and storage. These filters will then be conditioned after the sample filter has finished its collection and weighed again. This mass difference accounts for the mass change of the sampled filter under the same conditions. (note: this mass difference should be less than or equal to 60 µg to comply with the guidelines)

3.3 Setup of testing for particle loss through a sampling system

In addition to a filter handling and weighing it is important to consider and the potential impact of the sampling system being used. The sampling systems used when measuring LNG at field sites

may cause particle losses before they reach the detector or filter leading to an underestimate of particle concentrations within the sample gas. In order to determine what these losses may be a controlled particulate penetration test must be recreated under laboratory conditions.

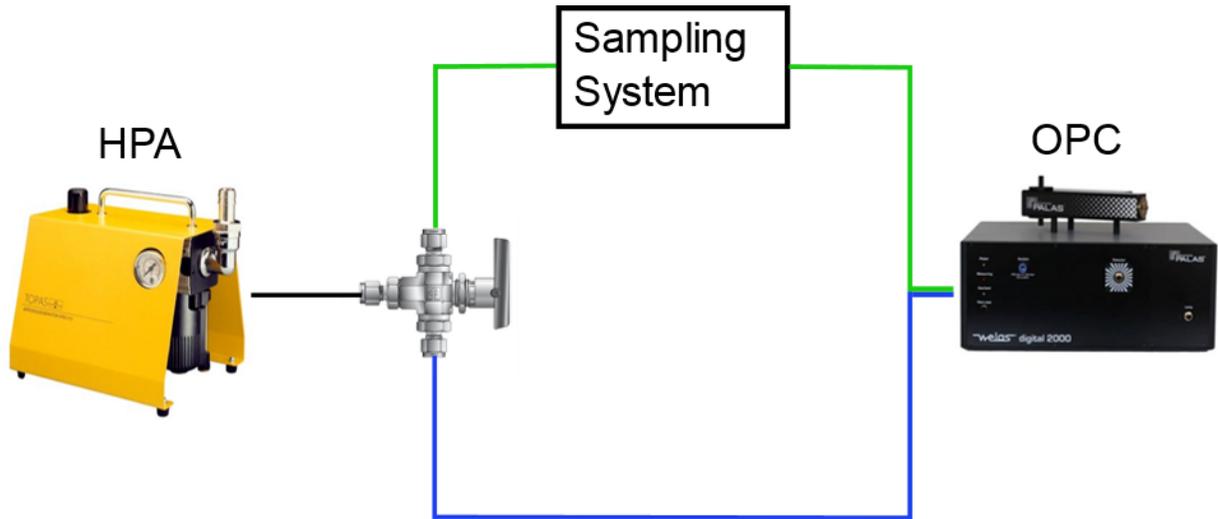


Figure 5: Example setup to determine the particle losses through a sampling system.

There are three major issues to overcome in order to be able to do this effectively:

3.3.1 Generation of particle laden LNG in the laboratory

One issue is to generate a stable particle concentration of a known size distribution in gasified LNG. The primary difficulty with this is that it must be generated in situ as particles added to a pre prepared cylinder of LNG would be lost to the walls of the cylinder. Additionally, generating particles above 1 micrometer to add directly to a gaseous LNG stream is non-trivial. Increased pressures, above atmospheric, are generally required to aerosolize larger particles. One method to achieve this is, to use a high pressure atomiser to generate a stream of LNG laden with polystyrene latex particles. These particles are characterised under electron microscopy to determine their size distribution. Size traceable particles are available from for example NIST. The generation of particles above 1 μm becomes very difficult at atmospheric pressure. Therefore, in this pilot study a High-Pressure Atomiser (HPA) was used to generate particles in the region of 4 μm in diameter. One major advantage of using an atomiser such as this is that it does not require electricity and so is intrinsically safe for flammable gases such as LNG.

Measurement of particulate concentration through a complimentary real time technique

Although mass collection on filters and their subsequent weighing is ideal for particulate mass determination in LNG, it is unsuited to a laboratory loss determination test. Here it is much more advantageous to use a real time detection technique. An Optical Particle Counter (OPC) can be used to measure the particle number and size distribution of the generated aerosol in real time. The major advantage that an OPC has over other real time instruments such as a Condensation Particle Counter (CPC) is that it is a light-based technique requiring no physical interaction with the carrier gas. As light is used behind a transparent shield to characterise the particulates, interaction with the carrier gas is minimised. Some OPC models have a separate measurement head (e.g. Palas Promo 2000 P). This makes them ideal for measurements at site where a flammable atmosphere could cause an issue. In these models, as only light is transmitted between the measurement head and the instrument body, this makes the head intrinsically safe and perfect for use with a flammable gas such as LNG.

3.3.2 Determination of particulate losses through a sampling system

A combination of HPA and OPC can be used to determine particulate losses in a sampling system. This is especially important if a regulator is required to reduce the pressure or flow from the LNG station.

Before undertaking the following procedure in the laboratory please ensure that a hazard analysis is performed. Any sampling system must also comply with PED and ATEX directives, and in addition, a hazard and operability (HAZOP) study needs to be performed when installing in site installations. Local (non-European) standards and regulations should be complied with.

Important points to consider for your laboratory risk assessment are:

- A high-pressure head must be obtained for the OPC
- The tubing and joints must be suitable for high pressures
- Make sure to leak check the system
- Do not perform the procedure alone
- LNG is explosive
- High pressures are being used

At NPL the following apparatus were used:

Table 2: Acronyms and instruments used in the testing for particle loss through a sampling system

HPA	High-Pressure Atomiser	Topas ATM 210
OPC	Optical Particle Counter	Palas Promo 2000 P
SMPS	Scanning Mobility Particle Sizer	TSI 3080
CPC	Condensation Particle Counter	TSI 3775
PSL	Polystyrene Latex Spheres	NIST PSL

3.3.3 Validating the OPC against other particle sizing instruments and known PSL sizes

This initial test is used to check that the HPA generates a stable aerosol and to validate the OPC against an SI-traceable SMPS. The SMPS is a device designed for the measurement of ultra-fine ambient aerosols. As such this test must be conducted at pressures below 1 Bar and using nitrogen as opposed to a flammable gas. Also, the SMPS system is only able to measure particulates of up to 1 μm . The initial testing at NPL used a nitrogen pressure of nominally 1 bar and 900 nm PSL (0.903 μm +/- 0.012 μm). This step allows a concentration comparison between the SMPS and the OPC. The layout for this system can be seen, illustrated in Figure 6.

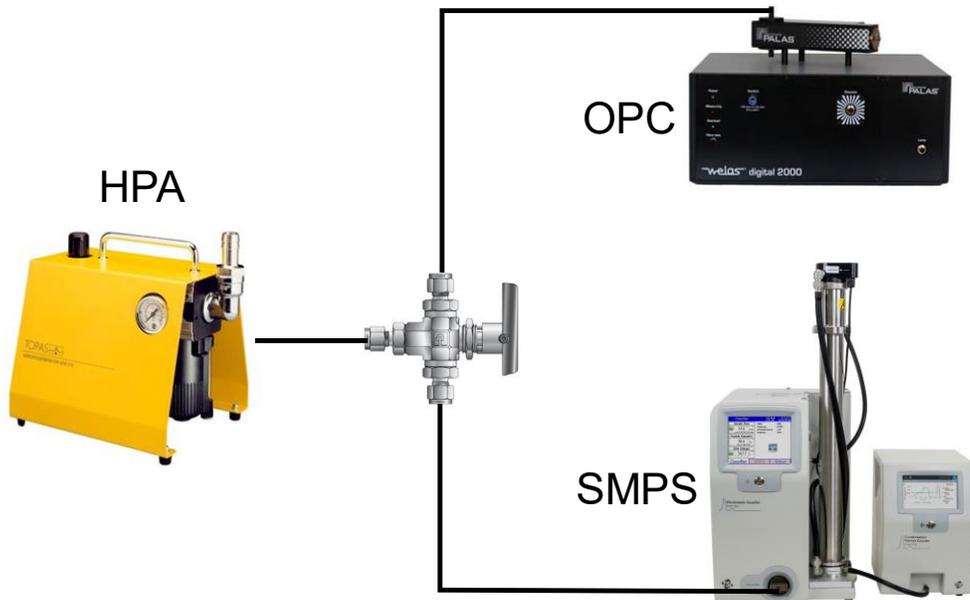


Figure 6: Setup to check the OPC against calibrated SMPS system.

3.3.4 Test OPC with High Pressures and PSL

The next step is to remove the SMPS system and generate larger particulates in a stream of nitrogen at an increased pressure. Before using LNG, PSL is tested with nitrogen through the HPA and measured by the OPC. This is to assess the performance of the instruments under pressure without the added risks of using LNG. Higher pressures are needed to achieve the larger particle sizes and higher concentrations of particles within the gas. Once this has been shown to be both safe and effective the nitrogen can be replaced with LNG. The size traceability for this measurement comes from the NIST traceable PSL beads. The OPC number concentration (and therefore mass) traceability is more difficult to obtain. Recently it has become possible to achieve direct SI traceability through an NMI such as METAS. Without this it is only possible to check the particle number concentration at lower particle sizes (up to 1 μm) using an SMPS comparison shown in Figure 6.

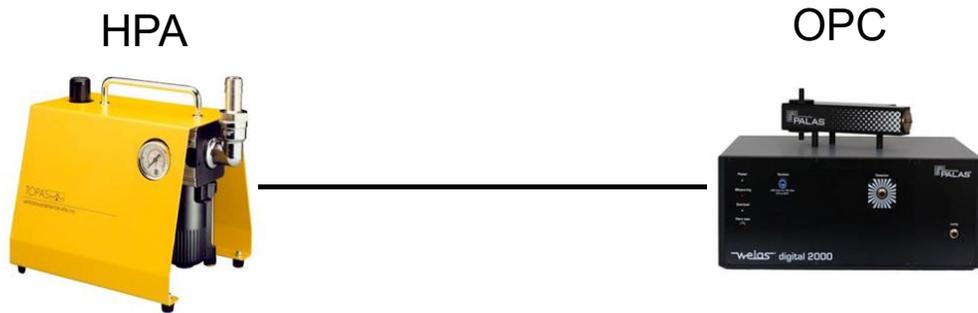


Figure 7: Setup of HPA and OPC to be used before LNG is introduced.

3.3.5 OPC and Filter mass equivalence

The next stage is to add a 3-way switching valve to the system. In one position the 3-way valve allows the particles to pass through the OPC to determine the number concentration and size distribution. In the other position the 3-way valve allows the aerosol to pass through a filter. By using the density and assuming the stability of the HPA source, the results of the OPC and the mass collected on the filter can be used to determine the equivalence of the two different techniques.

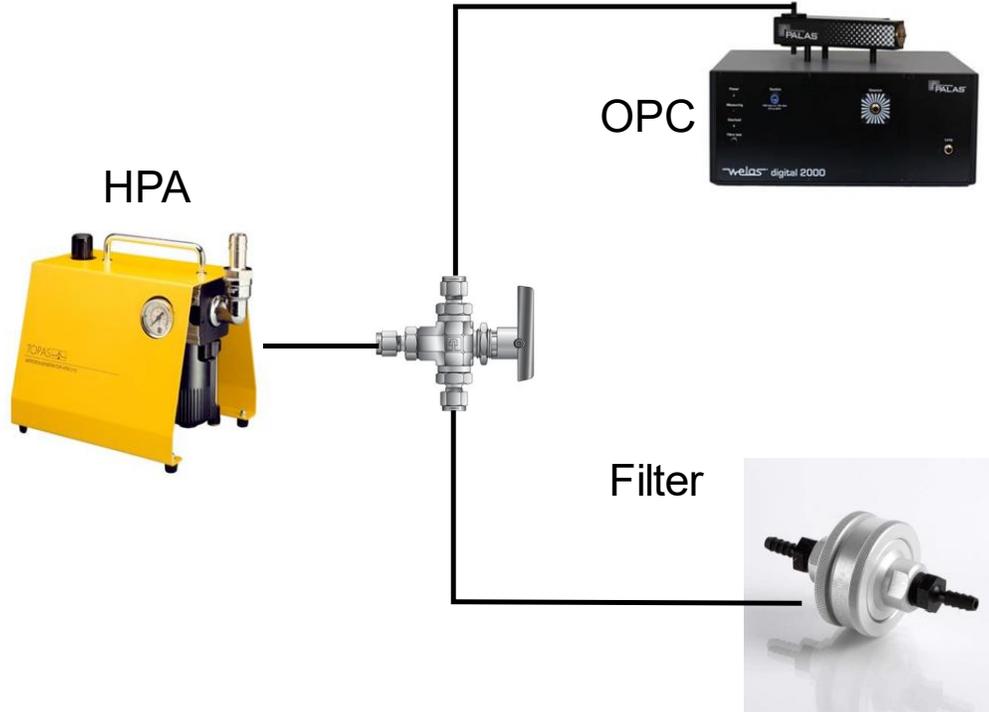


Figure 8: Setup to test the equivalence of OPC readings and the mass gained by filter. The three-way valve will be flipped between the two systems and then the results are compared.

3.3.6 Build a sampling system testing rig

The test rig for assessing the sampling system needs to be built to hold pressurised Methane/Nitrogen mix, so appropriate materials such as stainless steel should be used and the system must be fully leak checked with an inert gas such as nitrogen before use. With this setup the OPC will be constantly measuring, but gas doped with particles will only flow down one branch of the system. The sampling system may be a regulator or other valves and tubing used for sampling at the LNG refuelling station.

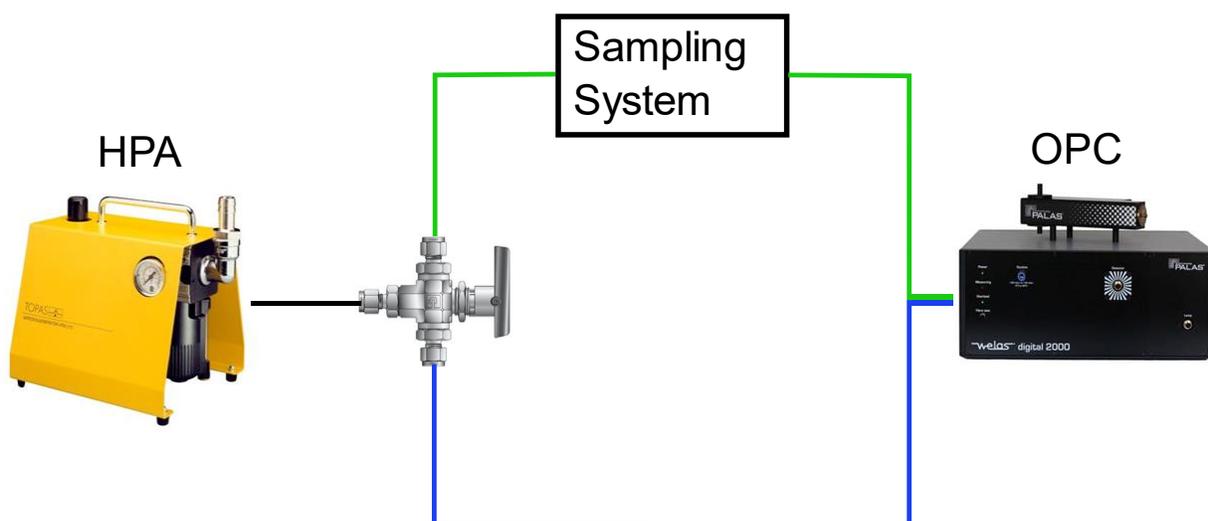


Figure 9: Final setup to determine the particle losses through a sampling system. Green route indicates where the aerosol flows through the sampling system, the blue route indicates where the aerosol does not flow through the sampling system.

3.4 Determination of losses from a sampling system

The simple equation to determine the losses within a sampling system is very similar to that used in the filter mass determination. By using a 3-way switching valve and identical lengths and diameters of tubing on both branches, we have assured that the only difference between each branch is the sampling system itself. As the generator can be regarded as stable and the OPC is unaffected by sample pressure the difference in the particle concentration when the 3-way valve is switched will be the losses within the sampling system.

$$PL = p_{clear} - p_{system}$$

Equation 6

where:

PL	=	Particulate concentration loss within the sampling system
P_{clear}	=	Particle concentration at the OPC down the clear branch
P_{system}	=	Particle concentration at the OPC down the System branch

In order to fully characterise particle losses within a sampling system a suite of particulate sizes and concentrations should be considered.

4 – Conclusions

This Good Practice Guide is intended to be used as helpful document for those wishing to set up their own measurement system for the determination of particulates in LNG. In line with the objectives set out in the LNG III EMPIR project, this guide has highlighted the considerations, quality control and procedures required for weighing LNG particulates from a filter weighing methodology. It has described a method for the accurate measurement of the collected particulate mass on filters building on the expertise gained from the area of ambient air monitoring. It meets the requirements for filter storage; conditioning and weighing that are laid out in the ambient air standard EN 12341:2014 [3]. Further to this it has offered guidance on the determination of particulate losses within sampling systems used at LNG refuelling stations. Unfortunately, due to Covid-19 and the subsequent laboratory closures it was not possible to generate experimental results for the procedures recorded in this document. Therefore, although these procedures have been assessed for proof of concept, a full validation on real World LNG samples has not been possible. As factors such as flow rates and pressures are highly dependant on the sampling systems and filters used these on-site variables have also not been considered here. Although the original task asked for a list of recommendations from this document, I feel that this would be an oversimplification. This Good Practice Guide has instead highlighted many of the issues and pitfalls associated with setting up traceable measurement, from onsite sampling to the final mass value for particulates in LNG/LBG.

5 – References

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