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Mercury Management Study 2013 NAM GTS

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1 Introduction

1.1 Mercury in Gas

Mercury (Hg) is a rare naturally occurring metal. Volcanic activity brings mercury to the surface of the Earth, depositing it throughout the crust, and in soil, water and air crust (Van der Poel, 1996). Mercury was first observed in gas fields in 1960. Gas fields that have volcanic rock beneath the reservoir rock will frequently host mercury in gas. An example is Rotliegend sandstone, the reservoir rock for the Groningen field in the Netherlands. (Van der Poel, 1996) (Achterberg & Zaanen, 1972).

Because mercury is toxic, parties related to the supply of gas have been interested in the safety of their gas consumers. Along with others, these parties undertook studies to assess and evaluate consumers' exposure to mercury from gas. Using the latest evaluation techniques, they concluded that gas delivered to consumers meets health standards set for mercury exposure.

The conclusions from studies are regularly reviewed. This is to ensure they are valid given improvements in mercury measuring technology, and changes in the treatment of gas. Reviews also ensure adherence with latest health standards, and the public's expectation for the protection of health and the environment.

1.2 Mercury and Health Effects

Health effects from mercury depend on the concentration and duration of exposure. Mercury has a varying impact on health for different age groups (e.g. foetus, children, and adults). This fact has been taking into account for exposure norms prescribed by the RIVM (Rijksinstituut voor Volksgezondheid en Milieu/ Netherlands National Institute for Health and Environment). For mercury in air, the RIVM advises a short term exposure limit of 10 µg/m3 per week. Their advice for a safe level of long term exposure in an indoor air environment is much lower, at 0.05 µg/m3 (RIVM, 2011). This is to take precaution for the risk of mercury accumulating in the human body.

Adverse health effects could develop if a person is exposed to mercury above the advised threshold. In particular, the central nerves system and kidneys can be affected. Symptoms include tumours, mental disturbances or proteinuria (the appearance of light proteins in urine indicating a disturbance in the kidneys (RIVM, 2011)).

Health advice in relation to mercury has changed considerably over time. Mercury was commonly used for dental fillings up until the 1990s, as well as in thermostats in homes. Advances in the understanding of mercury have brought an end to this, as the health risks are now deemed to be too high. Consequently, products containing mercury are subject to increasingly stringent regulation (Lemstra, 2013). Moreover, media has educated the general public about the risk of using products containing mercury (example: RADAR TV broadcast regarding mercury in fluorescent lights, 2012).

1.3 Initiation and Aim of TOR 'Kwik beheersing studie 2013'

A review was requested by GTS and NAM management in 2013 based on KEMA measurement findings that showed higher concentrations mercury presence in Groningen gas further distributed in the Gasunie national transport grid than previously observed and anticipated (KEMA, 2012).

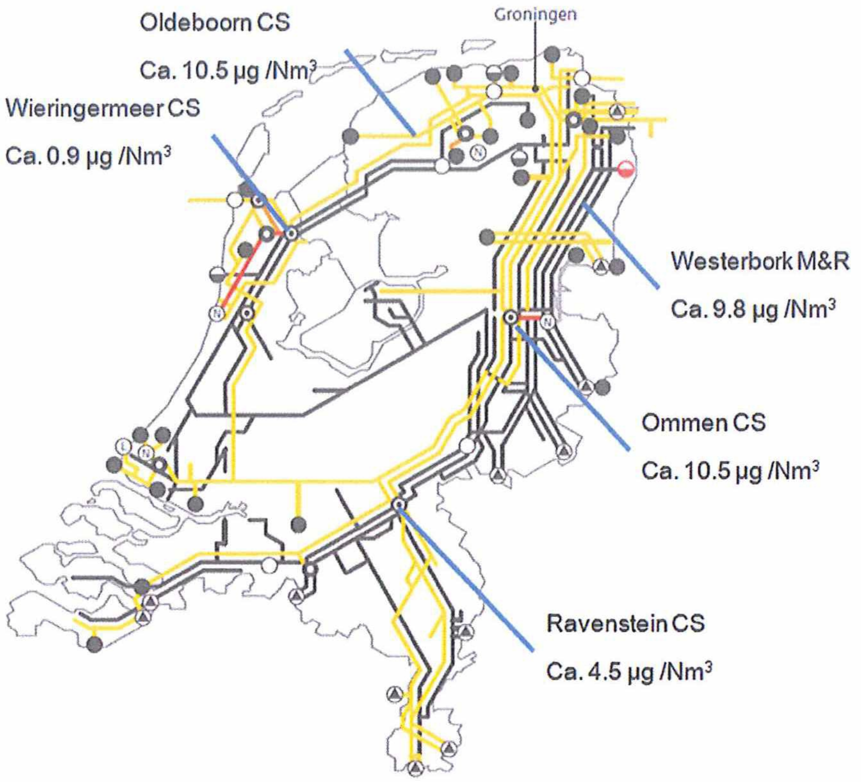

Figure 1 Mercury concentrations in GTS grid in 2012 (KEMA, 2012)

The aim of the studies was to improve understanding of mercury in gas in the supply chain in support of the development of a 'kwik beheersplan' / mercury monitoring programme. The specific studies were defined in the Terms of References (TOR) signed by GTS and NAM.

Scope

1) Het uitwerken van investeringsvoorstellen voor het verwijderen van kwik uit het aardgas op verschillende locaties in de keten bij NAM en GTS teneinde de optimale verwijderingsplaats te kunnen vaststellen. Mate van uitwerking per verwijderingsplaats wordt nader vastgesteld tijdens de studie.
2) NAM heeft in het kader van verdere kwik verwijdering in 2013 dieper koelen geïmplementeerd op de Groningen clusters. De reductie voor kwik wordt geverifieerd middels metingen eind 2013, begin 2014.
3) Het onderzoeken van de kwik verwijderingtechnieken in relatie tot de minimalisatie verplichting (Nederlandse Emissie Richtlijnen) en Best Available Technique (BAT).

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4) Opstellen van document(en) met mogelijke beheersmaatregelen en de daarbij behorende kosten en efficiëntie.

Figure 2 Mercury studies defined in TOR (2013) between GTS and NAM

GTS and NAM agreed that the review would focus on Groningen gas. There were several reasons for this. Firstly, the Groningen field is the largest gas producing asset in the Netherlands. Secondly, Groningen gas has a high concentration of mercury relative to other fields. Because of this, any measures required to reduce the end user's exposure to mercury would be most effective by concentrating on the G-gas system. Furthermore, the safety of domestic consumers was seen given special attention, all of whom use Groningen gas for heating and cooking etc. In contrast, gas streams from other fields are either hi-calorific (supplied to industry) or relatively small. Small low-calorific gas streams are generally mixed/diluted within the larger G-gas stream.

2 Mercury Concentration in Groningen Gas

Groningen gas contains a mercury concentration of ~180 µg/Nm3, when measured at the wellhead. This gas is mainly produced from the rotliegend reservoir, and has had a stable concentration of mercury over time. In the Groningen gas treatment process, more than 90 % of the mercury content in the raw gas is removed during the gas treatment process. Low Temperature Separation (LTS) is used to treat the dry gas, so as to bring it up to the sales specifications. The figure below shows the mercury concentration in the LTS gas treatment process.

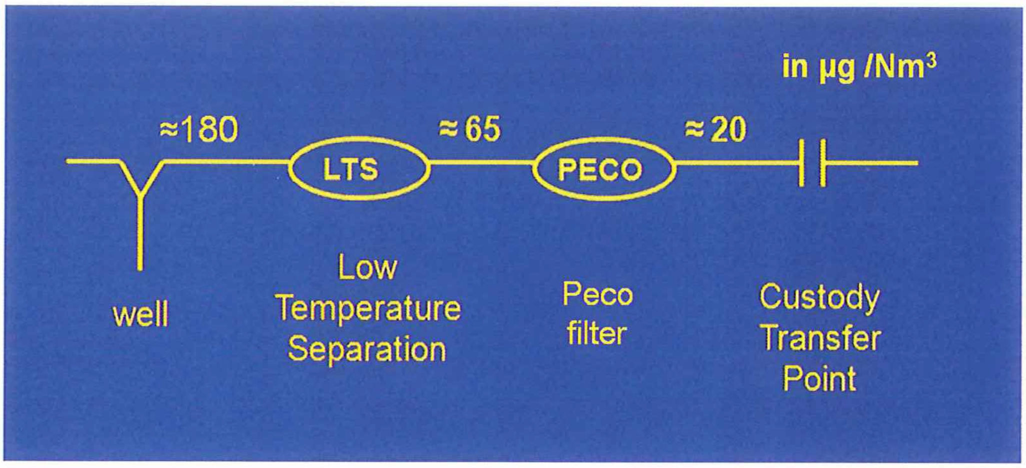


Figure 3 Presentation Mercury study workgroup (2010)

2.1 Groningen Sales Gas is Reduced Hg Concentration at OVs: < 0.3 – 11 µg/Nm3

The mercury content of Groningen gas is measured at the point of entry to the GTS system (Custody Transfer Point). To arrive here, gas first undergoes gas treatment before leaving the production clusters, and then travels through the Groningen transport ring to one of the seven Groningen OVs, where it will enter the GTS grid as 'Sales Gas'.

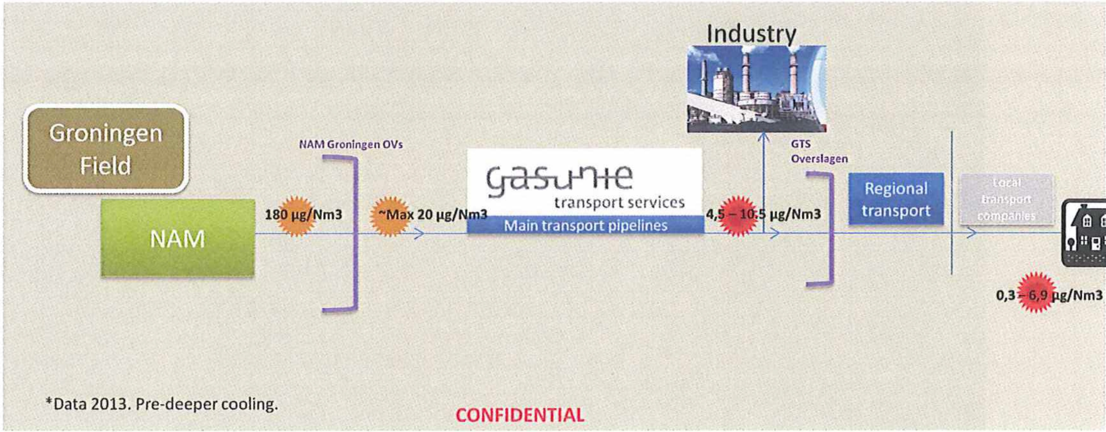
OV	Min	Max	Median	Measurement Year 2013
EKR	0,48	16	5,95	4,1
EKL	3,3	16	8,7	8,2
SAP1	3	17,0	5,2	X
SAP2	0,4	12,0	4,9	0,4
TJU-N	1,3	13,0	6,9	<0,3
TJU-Z	2,4	17,4	13	11
TUSS	0,9	18	6	4,6

Figure 4 Mercury concentration Groningen gas at OVs (year 2007-2013) in µg/Nm3

Measurements of mercury in Groningen sales gas show a wide range of results. This is largely dependent upon temperature and flow rate. In 2013, NAM implemented a process modification to reduce the mercury content of Groningen gas. To do this, the treatment temperature of the LTS unit was reduced on the clusters from -10°C to -14°C. This modification reduced the level of mercury in sales gas by an average of ~3 µg/Nm3.

2.2 Mercury Concentrations in Gas Supply Chain

The Groningen field has been feeding the GTS pipeline system with sales gas for decades. Over this time, several measurements of mercury were taken at different points of the supply chain. The location and results of these measurements are in the figure below. This shows that mercury concentrations are lower at the point of exit from the GTS grid than at the point of entry. Studies have tried to explain why the concentration of mercury in gas falls once passed through the GTS grid, however, have not delivered any firm conclusions. There is evidence to support the hypothesis that mercury is adsorbed by the steel of the pipelines.



The concentration of mercury in gas delivered to domestic consumers was measured in 2013. This showed that gas delivered to households contain low levels of mercury (KEMA, May - July 2013). This was the first observation of such a phenomenon, despite prior tests conducted in 2010 on NAM premises (testing points: NAM lab, NAM Kitchen) (NAM Laboratory, 2010). One hypothesis for this change is that the adsorption capacity of the GTS grid has reduced with cumulative use over time. This will be discussed further in chapter 7.

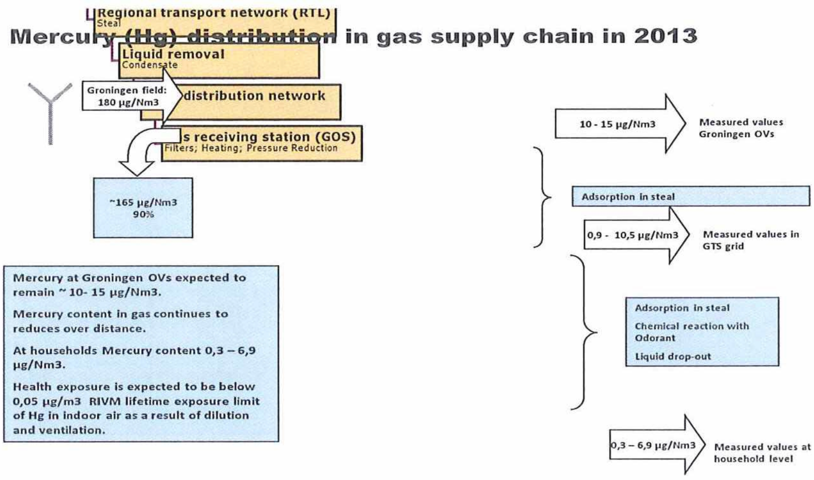


Figure 5 Mercury distribution of Groningen in gas supply chain (2013)

3 Regulation

3.1 Gas Quality Regulation in The Netherlands

GTS performs the role of the Dutch National Transmission System Operator (TSO), as appointed by the minister of Economic Affairs. The role of the TSO originates from the Dutch Gas act, supplemented over time by associated Technical Codes set by the ACM (Authority Consumers and Markets). The GTS network[1] transports all gas produced by NAM to end-users. It is the responsibility of GTS to ensure that gas supplied to end-users is compliant with agreed quality specifications. To meet this responsibility, GTS may set the quality requirements for gas entering their system. Currently, there are no codes, regulations or bilateral agreements that set a threshold for mercury content in gas.

GTS is developing and seeking to enter into bilateral Grid Connection Agreement's (GCA's) with all gas providers that deliver gas to the GTS grid (Status: March 2014). The GCA's will capture the required gas conditions (pressure/temperature) and gas quality at the point of entry. Beyond this point, the producer has no direct control over the quality or the destination of their produced gas. Instead, it is GTS who controls the gas streams, with control over the mixing of gas streams and gas routes. However, GTS's ability to mix gas of different quality within the grid is constrained by the supplier's choice of entry point and the location of the consumer.

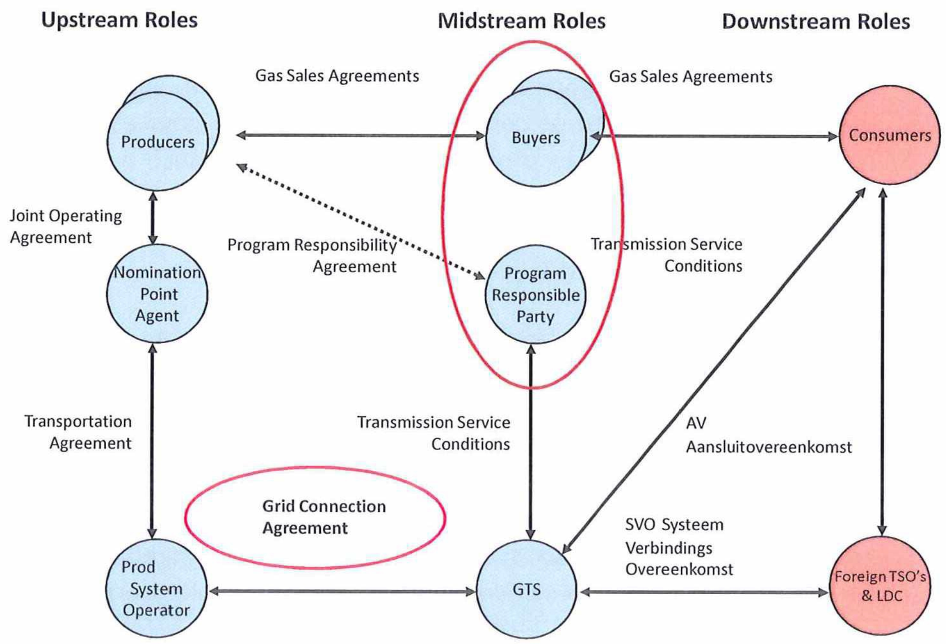


Figure 6 Gas quality responsibilities in Dutch gas supply chain

[1] Possibly via adjacent gas distribution networks (DSO's, also known as local distribution companies LDC) or via neighbouring TSO's (NNO's). The corresponding contracts are SVO (Systeemverbindingsoverenkomst) with DSO's and GCA (Grid Connection Agreement) with TSO's.

3.2 Regulation related to mercury in gas

As a toxic substance, national and international regulators see mercury as a priority for regulation. Over the past years, most regulators have reduced the threshold of mercury concentrations.

Despite this trend of tighter regulation, the Netherlands has not yet issued a specific threshold for mercury in natural gas. When assessing gas, other (environmental) regulations for mercury must be interpreted and applied. In the Netherlands, these include:

- REACH/CLP
- Best Available Technique (BAT)
- Minimization principle

3.2.1 REACH

REACH[2] is the European Regulation on chemicals and their safe use. It deals with the **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances. This regulation entered into force on 1 June 2007 and is implemented verbatim via the Dutch Environmental Management Act[3]. The aim of REACH is to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances. The REACH Regulation gives greater responsibility to industry to manage the risks from chemicals and to provide safety information throughout the supply chain on these substances. REACH also applies to mercury in sales gas.

Following REACH, the following statements can be made:

- REACH address hazardous substances. When inorganic compounds of mercury are contained in a mixture at concentration levels at or above 0.1 % by volume, the mixture would classify as a hazardous substance. In such a case, the marketing of such a mixture would be restricted to professional users and banned from delivery to the general public. This is based on the European Regulation on Classification and labeling 1272/2008/EC (CLP).

- REACH holds the regulations for Safety Data Sheets (SDS); the means of communicating information on substances to all parties in the supply chain. The supplier shall provide the recipient at his request with a safety data sheet where a mixture does not meet the criteria for classification as hazardous, but contains [..] in an individual concentration of 0.1 % by volume for gaseous mixtures at least one substance posing human health or environmental hazards. An SDS need not be supplied where hazardous substances or mixtures offered or sold to the general public are provided with sufficient information to enable users to take the necessary measures as regards the protection of human health, safety and the environment, unless requested by a downstream user or distributor.

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[2] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

[3] Environmental Management Act, chapter 9

NAM has deemed that mercury as an individual component in natural gas is far below the threshold of 0.1 % volume, with a concentration of 0.000000000147 vol% (an equivalent of 20 µg/Nm3) (NAM Laboratory, 2013). Consequently, NAM is compliant with REACH, and NAM does not have to include mercury in the SDS for natural gas.

3.2.2 Best Available Technique

Best Available Technique (BAT) is a principle in environmental legislation. It is used to express the targeted level of prevention. The BAT Reference Document (BREF), 'Mineral Oil and Gas Refineries'[4], uses the BAT to address mercury reduction, stating: "*Some of the gas fields contain mercury vapor in very low concentrations. This mercury is removed from the gas in a 'cold trap' (e.g. by gas expansion) and recovered as a mercury containing sludge. A specialized company processes this sludge by treatment in a vacuum distillation unit".*

The associated BAT-conclusion is: "D*ispose of mercury recovered from raw natural gas (if present) in an environmentally acceptable way*". The BREF is currently under revision and in the latest revised BREF (July 2013) proposal (still under consultation) the BAT-conclusion (#43) is: "*In order to prevent emissions of mercury when present in raw natural gas, BAT is to remove it and recover the mercury-containing sludge for waste disposal"*. This change of wording could signal that deep cooling alone would not be considered sufficient in the future and that additional filter removal is required. This should be tested against the cost-effectiveness and other effects of BAT (similar to step 2 of the minimization below) or alternatives have to be assessed according the 'Document on Economics and Cross-Media Effects.'

3.2.3 Minimization Principle

Beyond BAT, The minimization-principle[5] applies to mercury since mercury is classified as 'minimalisatieverplichte stof' (MVP-1) by the Dutch government regulations (NeR, Nederlandse emissie Richtlijnen). It prescribes prevention or subsequent reduction as per 5 consecutive steps:

Step 1: Establishing the Current Emissions
Step 2: Assessment of the Reduction Techniques
Step 3: Assessment of Impact on the Environment (Emission)
Step 4: Implementation of Measures
Step 5: Continuous Assessment and Periodic Reevaluation

<u>Step 1:</u> Establishing the Current Emissions

In order to know if emission regulations are met, an emission assessment is required. NeR regulations state that an emissions assessment is required for any gas with a mercury mass flow at or above **0.15 g per hour**. Groningen sales gas has a mercury mass flow of 47 g/hour (Ref. EP201310206381), and is therefore subject to an emission assessment. The test was conducted on a concentration of Groningen sales gas of 0.01 mg/Nm3 that had

[4] Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries, paragraph 4.17.7, European Commission, February 2003

[5] Nederlandse Emissie Richtlijnen, NeR, www.infomil.nl, paragraph 4.15

undergone Deep Cooling. The results of the emissions tests for Groningen gas were significantly below the The NeR mercury limit of **0.05 mg/m3**.

Step 2: Assessment of the Reduction Techniques

Beyond Deep Cooling, further techniques are available to remove mercury from gas. NeR requires the reduction technique to be cost effective. This means that the annual investment and operating cost is not disproportional to the marginal reduction of environmental impact. Given this, NAM should consider Filter Removal, which utilized active coal bed filters to remove mercury from gas.

Cost Effectiveness: Coal Bed Filter Removal

The NER provides a method to evaluate the environmental cost-effectiveness of an emission reduction project. This enables a company to compare alternative reduction techniques with one another in order to review cutoffs select and appropriate reduction techniques. There is no known prior precedence to establish an appropriate cut-off point for cost effective removal of mercury from gas. The nearest available reference case is 'Mercury in waste water', which has a cut-off point of 2.327 euro/kg avoided mercury. Filter Removal requires a capital investment of EUR 421 mil. This covers installation of filters at NAM sites (clusters, units or OVs), and will remove a total of 425 kg of mercury from gas per year. This gives a cost of 207 euro per kilogram mercury removed for the remaining lifetime of the field. With mercury removal costs from filters being far **above** the reference case of Mercury in waste water, this emission reduction project is not considered cost effective according to the NeR guidelines.

Previous studies to assess the impact of emissions on health and the environment have assigned mercury a relatively high weight factor. One such study was a Ranking of Environmental Investment Model (REIM), jointly developed by Industry and Dutch government as part of a covenant 'Company Environment Plan 2007 – 2010'. According to this obsolete investment model, existing installations have a mercury reduction cut-off cost of 8 EUR/kg mercury avoided. The REIM sets the abatement cost of one EIU at 8 Euros. As one kilogram of mercury has an EIU of 7.648[6], filter removal of mercury costs approximately 61 EUR/kg mercury avoided. This places the cost of mercury abatement far above the investment cut-off point for cost effective reduction set in the 2007-2010 REIM.

Considering the standards set in treatment of mercury in waste water, and conclusions from industry studies, NAM cannot justify active Coal bed filters (adsorption) at its clusters. This is because this technique is not considered cost effective within the framework of the NER minimization principles. To be sure of this conclusion, the Filter Removal investment program was further evaluated under the assumptions of the 2007-2010 REIM covenant. Again, the conclusion was that the required investment is significantly higher than the cut-off point agreed in this covenant.

Ref. NER Cost effectiveness calculation method, attachment 1:
Total net yearly cost: euro 88.140.000 Total yearly emission reduction in kg: 425 kg Cost per kg avoided mercury emission ; **207.000 euro/kg mercury avoided** *Reference cut-off point mercury in wastewater: 2327 euro/kg mercury avoided*

[6] REIM Mercury Preference Factor per One Tonne (EIU): 7648

Step 3: Assessment of impact on the environment (emission)

RIVM have set an intervention value for lifetime exposure to mercury. For indoor air, the intervention value is 0.05 µg/m3. Based on household measurements taken by KEMA in 2013, and the results from an emission calculation model, it can be concluded that the mercury concentrations in gas for domestic use will not exceed RIVM's intervention value. This study is explained in more detail in chapter 4 'Household Exposure As Result Of Mercury in Groningen Gas'.**Step 4: Implementation of Measures**

NAM acts upon the principle of 'Best Available Technique' (BAT) by applying Deep Cooling to remove mercury from Groningen Gas. Because there is no specified lower temperature for Deep Cooling, NAM applies the operating limits of their existing facilities as the low temperature. According to the NeR and (old) covenant, NAM is not required to act upon the Minimization Principle by installing Active Coal bed filters (adsorption) at Groningen clusters, for reasons of cost-effectiveness and existing cut off points.

Step 5: Continuous Assessment and Periodic Reevaluation

Although NAM does not (have to) act upon the minimization principle now, the NeR requires a re-assessment every five years to establish if the processes in place are still compliant. This re-assessment of the compliance should take into account the following factors:

1. Level of mercury in NAM Groningen sales gas,
2. Mercury emissions at households (below RIVM lifetime exposure norm of 0.05 µg/m3)
3. Change in mercury removal techniques (e.g. becomes more efficient)
4. Change in CAPEX/OPEX cost of mercury removal technique

3.3 Conclusions

NAM has reviewed existing regulations related to mercury in natural gas. They are compliant and act upon requirements. Regarding BAT requirements, NAM complies by using Deep Cooling in its clusters to remove mercury from Groningen gas. Regarding the Minimization Principle, NAM complies by re-assessing the viability of Filter Removal every five years, along with other reduction techniques. In accordance with the NeR's guidance for applying the Minimization Principle, the latest review demonstrated that filter removal at NAM locations is not justified.

4 Household exposure as a result of Mercury in Groningen gas

There are several categories of consumers of Groningen gas. These are in both the Netherlands and neighbouring countries: Industry, Intensive Agriculture and Domestic Users (Van der Poel, 1996). Dutch Domestic Users are the largest consumers of Groningen gas. This study therefore focuses on Domestic Users, and theoretically models the possible exposure to mercury an individual may receive as a result of Groningen gas consumption in a household setting.

4.1 Results

4.1.1 KEMA Measurements Mercury in Gas at the Household Level

Measurements of Mercury levels in Gas at Dutch Households: Levels in µg /Nm³

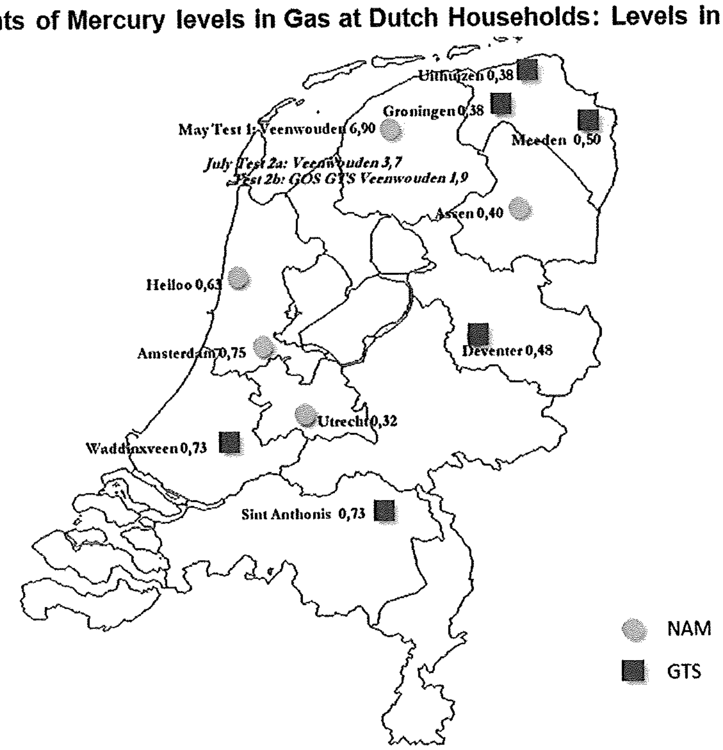

Figure 7 KEMA sample test May - July 2013

The figure above shows the location and result of each gas test conducted by KEMA for several sites in The Netherlands (KEMA, May - July 2013). From these results, KEMA observed that mercury is present in the gas consumed by Domestic Users. The gas tests were conducted in the period May-July 2013, and show values between 0.3 and 6.9 µg/Nm3. With respect to mercury content in relation to distance from source, earlier studies showed that mercury levels in gas reduce as the distance travelled in the GTS grid increases (KEMA, 2012). However, the latest results show no correlation between mercury in gas at households, and distance traveled in the GTS grid. This reason for this has not been studied, however, possible explanations may be variations of the age of the local gas distribution network, household's infrastructure, etc.

The highest measurement of mercury was 6.9 µg/Nm3, recorded in Veenwouden, Friesland. Neither KEMA nor GTS could explain this result. To understand more about the result, KEMA conducted a second tests at this location, and measured a lower level of 3.7 µg/Nm3.

Furthermore, the gas transported to this location was measured at the GTS Gas Delivery Station (Gasontvangstation GOS), showing a value of 1.9 µg/Nm3. The gas streams could not sufficiently explain the above findings. The conclusion from this is that there is incomplete understanding of how the mercury in gas behaves when transported through the GTS grid.

The mercury content of earlier measurements taken in the NAM laboratory in 1996 and 2010 were all below the detection limit of 0.3 µg/Nm3 (Van der Poel, 1996) (NAM Laboratory, 2010). In 2013, measurements of mercury in gas taken in the NAM laboratory were above the detection limit (0.4 µg/Nm3). Whilst more recent measurements show a higher mercury content, one cannot base a trend on these three samples alone.

4.1.2 Modeling Household Exposure

It is important to interpret the measurements of mercury in Gas within the context of exposure to domestic users. According to RIVM, mercury accumulates in the body over time. NAM developed a model to assess whether Domestic Users could be exposed to values above the RIVM lifetime exposure norm of 0.05 µg/m3 mercury in their home (NAM, 2014)[7]. An average indoor air quality above this norm would constitute a health risk. This theoretical study focused on assuming a worst case scenario with respect to the living conditions in the Netherlands. The aim was to test whether mercury content in gas would be safe for all users in all circumstances.

The model showed the following results:

- In the worst case scenario, the exposure to mercury is below the RIVM lifetime exposure norm. The worst case scenario is designed to produce the highest possible exposure to mercury from natural gas combustion by domestic users. This assumes living conditions where the domestic user is supplied with gas containing the highest observed levels of mercury content (20 µg/Nm3), that is then used to fire a gas boiler and cooking stove within a small enclosed space with poor ventilation. In this scenario, the average value of mercury in indoor air would be 0.03 µg/m3. Less extreme scenarios with more favourable domestic conditions can produce results as low as 0.0097 µg/m3.
- The highest observed measurement of mercury in gas in a domestic setting is nearly 1/5th the lifetime exposure norm of 0.05 µg/m3, as issued by RIVM (KEMA, May - July 2013). For worst case living conditions the exposure is 0.012 µg/m3. For other living scenarios, the exposure values vary within the range of 0.005 – 0.012 µg/m3. The low end of the range approaches the level of background mercury exposure in the atmosphere in The Netherlands (0.003 µg/m3).
- The RIVM norm is issued for the lifetime exposure to mercury. It does not address short term exposure to higher levels of mercury. However, the Municipal Health Authority (GGD) in The Netherlands uses the RIVM norm as their screening value to trigger more in depth investigations into air quality. When the GGD observe a value above the RIVM norm on a short-term test of air quality (e.g. 15 min), they initiate a further test of 24 hours. This test may conclude that although a 15 minute test exceeded the screening value, potentially due to the release of mercury from gas combustion, average exposure over the 24 hour period is below the RIVM norm. Short term peaks in mercury exposure of this low magnitude are not known to produce measurable implications on health. Given that combustion of gas at home is

[7] For further explanation of the modeling methodology, please read the report.

intermittent, not continuous, following patterns according to daily cooking and showering routines, the average exposure to mercury in a home using gas remains below the RIVM norm.

- The threshold for mercury in gas required to breach the RIVM norm in a worst case scenario setting was identified by applying stress testing to the model. The threshold for sales gas supplied to homes corresponds to a mercury content of 34 µg/Nm3. Among historic measurements of mercury in Groningen sales gas (at OVs), the highest observed value is 23 µg/Nm3. Therefore, there is no historic evidence of this threshold being breached.

GTS and Shell support these findings, which have also been shared with Exxon. Exxon's own assessment on the topic has differences due to assumptions reflecting American standards for housing and less stringent indoor air quality norms (Exxon Knickerbacker, N. , 2013).

It should be noted that there can be sources of mercury exposure not captured in the scope of this assessment. This model is a simplified model with the aim to focus upon the impact of Groningen gas combustion in a household. Beyond gas, there are other sources of mercury exposure, either in the short or long term. However, these separate sources, and their effect on human health, require specific health expertise best assessed by parties with professional expertise not held by NAM.

4.2 Conclusions and Recommendations

Groningen gas is deemed safe for household consumption. This conclusion was reached having understood the current health advice on mercury exposure issued by RIVM, the pattern and behaviour of gas usage in households, and the measured emissions of mercury from such use. Having modeled various usage scenarios for gas by Domestic Users, mercury exposure resulting from the combustion of gas remains significantly below the RIVM norm for maximum health exposure, i.e. a life time exposure of 0.05 µg/m3.

Regarding the RIVM norm being issued for lifetime exposure, it should be noted that short term tests may exceed the screening value set by the GGD. Although this is unlikely to be the case given the high average quality of living conditions in the Netherlands, there may be results from short term tests that trigger public concern if incorrectly communicated. If this happens, the need to refer to results from a 24 hour test should be clearly communicated.

5 Deep Cooling (-14 degrees Celsius)

5.1 Immediate Motive for Deeper Cooling Groningen Clusters

As part of the effort to reduce mercury content of the NAM sales gas in 2013, a process review showed that mercury levels could be reduced by lowering the gas treatment temperature on the Groningen clusters. Deep cooling is a gas treatment practice applied to upgrade the gas specifications to that needed for 'Sales Gas'. Via this process, liquids and mercury drop out at low temperatures and any remaining moisture is trapped in a filter installed after this deep cooling trap. During this process, more than 90% of the mercury is removed from the gas.

NAM could further increase the mercury removed from gas by lowering the temperature of the Low Temperature Separation (LTS) process. This is because the amount of liquid and mercury removed from gas is proportional to the extent of cooling subjected to the gas. NAM assessed the option of decreasing the temperature of the LTS process in the Groningen clusters from approximately -10 degrees to -14 degrees Celsius. Models showed that this change would result in a reduction of the mercury content by approximately 2 µg/Nm3 per degree Celsius. NAM proved this result by testing in January 2013, after which NAM management decided upon implementation on Groningen clusters.

5.2 Mercury Reduction Impact on Current Sales G-Gas Content

A test of the impact of a lower temperature in the LTS process was conducted on the Paauwen facility. This showed an indicative reduction of ~2 µg/Nm3 per degree Celsius at the outlet of the cluster (NAM, 21 February 2013). This is similar to findings in 2006 and 2012[8]. The test shows that the impact of deep cooling (at -14 degrees Celsius) comes with a higher OPEX cost (electricity consumption increase) and a reduction in gas capacity of < 1 million Nm3/day for Groningen clusters.

Groningen gas at the well head has a confirmed mercury content of 180 µg/Nm3, with spot measurements expected to fall within a 20% range. When LTS is dropped from -10 to -14 degrees, the content of mercury in gas is expected to reduce. The size of the reduction will be between 4 and 14 µg/Nm3, when measured at the outlet of one of the 20 clusters. This range of reduction observed across the 20 Groningen clusters may be for two reasons; firstly, the efficiency of the PECO filter will vary, and secondly, there will be uncontrollable variations in the methods and conditions for measurements. It should be noted that differences to the inlet of the LTS are unlikely to lead to differences after deep cooling treatment (NAM, 6 December 2010).

Based upon the averaging results for the cluster, this could lead to a total reduction of mercury in Groningen sales gas of around 5 µg/Nm3 at the NAM transfer stations (Dutch: Overslag stations, OVs).

Depending on which clusters feed into the NAM OVs, this could lead to a Groningen sales gas mercury content of ~10-12 µg/Nm3 when entering the GTS grid (NAM, 15 October 2013).

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[8] For more information please read EP report 'EP201302202974' and EP201305200115, by Richard Schaper

Measurements carried out in 2013 show that after deeper cooling, the Groningen OVs display values between < 0.3 – 11 µg/Nm3. The average mercury content in 2013 is 3 µg/Nm3 lower than the median content over the period 2007-2012 (NAM Laboratory , 2013).

5.3 Mercury Reduction Impact on Future Sales G-Gas Content

The success of lower LTS temperatures in reducing mercury in gas, however, it is important to understand if these results can be sustained.

If the operation modus of the LTS plant continues to cool gas to -14 degrees Celsius (spec of 80 mg/Nm3 PHLC), it is expected that the mercury content in Groningen sales gas leaving the OVs will remain around ~10-12 µg/Nm3 (NAM, 15 October 2013).

Other factors are very unlikely to change this achieved level of mercury, including the piping of the cluster being saturated or depletion of the Groningen field. The concentration of mercury in the wellhead gas is not expected to increase with lower reservoir pressure since it cannot be saturated with mercury under the reservoir conditions, and thus no liquid mercury phase exists (NAM, 6 December 2010). Consequently, the mercury content is not expected to increase with lower reservoir pressure as a result of depletion. Furthermore, the piping of the cluster is considered to be fully saturated. Therefore, the mercury level is dependent only on the LTS operating modus.

It is important to note that Norg gas has not been taken into account of the Groningen sales gas forecast for mercury content because it only produces intermittently at present (NAM, 15 October 2013). The NORGRON pipeline is expected to be operational by the end of 2014. At this point, NORGRON will be connected to the Groningen system, and it will send out Groningen gas. The gas is expected to have very low mercury content due to adsorption by the new pipeline that will be used for injection of Groningen gas into Norg.

6 GTS Technical study: Removal of Mercury in gas

6.1 Background of Study

NAM and GTS have assessed the feasibility of installing filters on a large scale to reduce the mercury in gas supplied to end users. Both upstream (NAM) and downstream (GTS) locations within the gas supply chain have been considered in order to assess which location is optimal for mercury removal, taking into account economic optimization and effectiveness in reducing exposure to end consumers.

6.2 Method of Comparison

The rule of six-tenths provides a method to obtain the cost of a similar item of different size or capacity. The earliest mention of this concept was found in a reference accredited to a December 1947 Chemical Engineering magazine article by Roger Williams, Jr. entitled "Six-tenths Factor Aids in Approximating Costs". The method basically is not more than statement that costs are proportional to size raised to the power 0.6. In the current study the rule of six-tenths is used to estimate the cost of the several scenarios for mercury removal plants based on adsorption with varying removal capacities. In formula:

$$\left(\frac{x_2}{x_1}\right) = \left(\frac{y_2}{y_1}\right)^{0,6}$$

x_1, x_2 are the cost of the existing and new installation or equipment respectively
y_1, y_2 are the capacities of the existing and new installation or equipment respectively

6.3 Results

Technical filter removal NAM-GTS ve

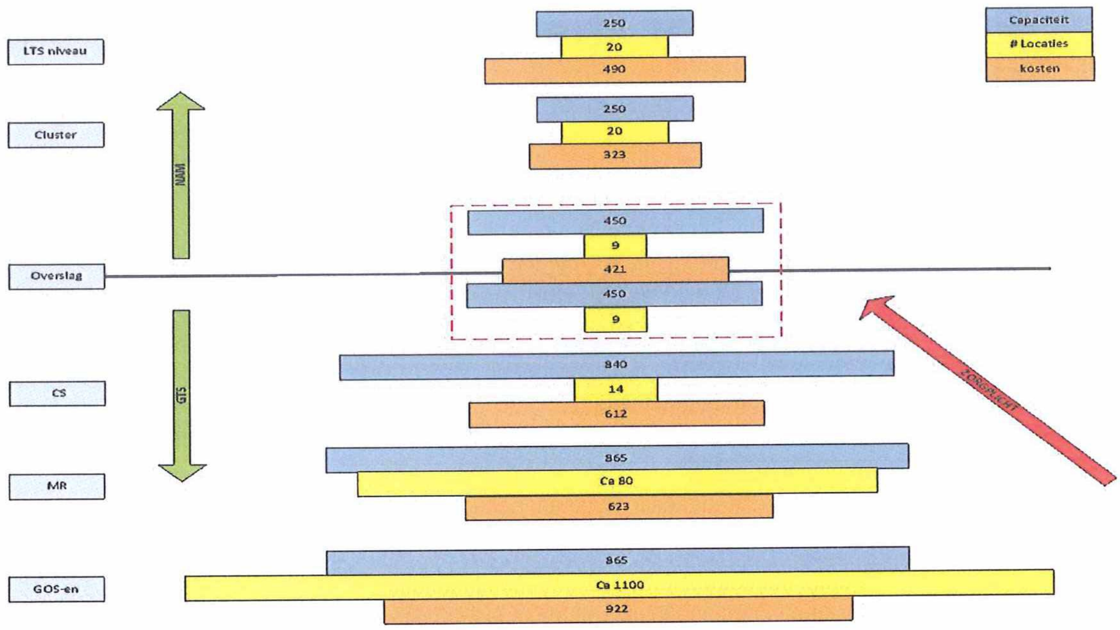

Figure 8 Comparison NAM and GTS for implementation filters (capacity, locations and costs) - picture by GTS 2013

7 Mercury Behaviour in a Natural Gas Transmission Line

This chapter covers the behaviour of mercury in gas when transported to customers through the GTS grid. Specifically, it reports the extent of mercury adsorption and desorption by the grid. Understanding the behaviour of mercury in the transmission line should be taken into account in order to implement an effective mercury reduction program that ensures the safety of household.

7.1 Background

NAM has produced gas from the Groningen field over decades. It was known that this gas contained mercury, however, earlier measurements had supported the working assumption that end users would receive gas free from mercury, or at least with an insignificantly low value. Later test results showing measurable levels of mercury at end users changed this assumption. It is not clear if the observation of mercury reaching end users is a change in conditions, or simply a change in understanding.

Groningen gas is transported to consumers by the GTS grid. Figure 9 shows the mercury content at various points in the gas supply chain. Differences in mercury measurements at different points of the transport grid suggest the grid has the capacity to absorb mercury, presumably by the scales and the steel wall. It is possible that the adsorption capacity of the GTS grid changes over time, and may reduce following saturation of the pipelines. This may lead to mercury reaching the end consumer, and may explain the new observation of mercury observed in gas delivered to domestic users (KEMA, May - July 2013).

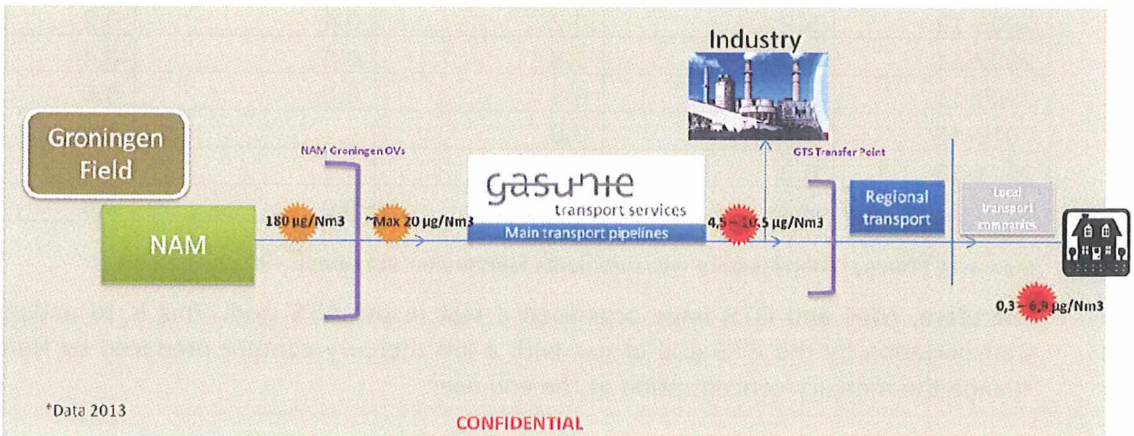

Figure 9 Mercury in gas in supply chain, data 2013

There are limited published studies concerning the behaviour of mercury in natural gas in the transmission lines. Any available studies are largely inconclusive. Similarly, variations in the GTS grid displayed below have not been fully understood.

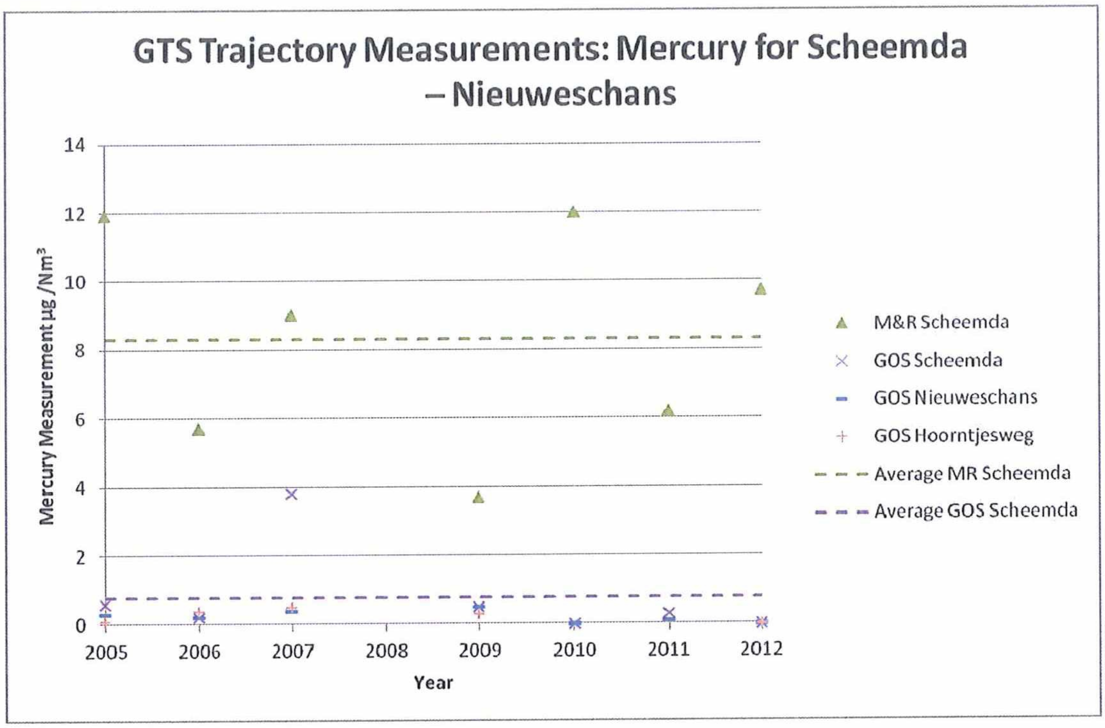

Figure 10 (Graph) GTS trajectory measurements mercury for Scheemda – Nieuweschans

Date	M&R Scheemda	GOS Scheemda	GOS Hoorntjesweg	GOS Nieuweschans
2005-11	11.9	0.6	0.1	0.3
2006-12	5.7	0.2	0.4	0.2
2007-11	9.0	3.8	0.5	0.4
2009-11	3.7	0.5	0.3	0.5
2010-12	12.0	0.0	-	0.0
2011-12	6.2	0.3	-	0.1
2012-12	9.7	0.0	0.0	0.0

Figure 11 (Table) GTS trajectory measurements mercury for Scheemda – Nieuweschans

Therefore, NAM and GTS have organised a test in the GTS grid. This is to understand, if transportation by the GTS grid of gas with a low mercury content produced by NAM, would change the mercury concentration at the end user.

The following *hypothetical* test outcome scenarios were considered.

Norg (N): 0 ug/m3 --> Eext (E): 10 µg/Nm3 (or any other significant value)

- TEST shows desorption takes place

N: 0 ug/m3 --> E: 5 µg/Nm3 (changing value)

- Desorption takes place, but does not show full break through, variations in desorption take place
- Requires more tests to explain trends and possible desorption reduction over time

N: 0 ug/m3 --> E: 0 µg/Nm3

- TEST shows no desorption takes place

7.2 Outline and Observations Desorption Test in GTS Grid (NAM, November 2013)

The selected pipeline from the NAM feeding point Sappemeer SAPO to the GTS Measuring and regulator station Eext (EEXT) has been in service for >40 years. The pipeline was originally coated with a flow-coating. It has received long term exposure to Groningen gas with an average mercury content of ca. 5 – 15 µg/Nm3. The total mercury load cannot be determined because only spot measurements are available. However, measurements in 2012 showed that sales gas transported on the trajectory Groningen – Westerbork – Ommen showed no decrease in mercury. This indicated that the pipeline was fully saturated with mercury.

The following observations have been made:

1. The measured mercury level at SAPO was close to 0 µg/Nm3. The measured mercury level at neighbouring feeding point TUSO was 4 - 6 µg/Nm3. Therefore, TUSO has been used as the main source of higher mercury content gas;

2. Initially there was a mix of TUSO and SAPO gas flowing to EEXT. The ratio cannot be determined. Therefore it is difficult to judge the results in this period;

3. In the period that gas storage NORG (NORU) was sending out gas, the time taken for gas to reach EEXT was considerably longer than expected. Also, it cannot be proven conclusively that only NORU gas reached EEXT during this period;

4. GTS has incomplete data for the hydrocarbon dew point analyser, due to storm inhibited data transfer from EEXT to Gasunie headquarters. This makes it difficult to interpret the first period of the test;

5. When switching from TUSO gas to SAPO gas and vice-versa, a direct response is seen in the mercury content.

7.3 Conclusion and recommendations

By conducting new tests and using historically available measurements, there are strong indications that desorption is unlikely to occur in the GTS grid. Should deposition take place, it is expected to be a very slow process in the quoted test circumstances (Matthey, 2005) (NAM, November 2013), which would result in a very slight increase in the mercury content of a low mercury natural gas passing through such a pipeline.

Nevertheless, some of the tests results still cannot be adequately explained. It is possible that flow-rate is an important variable in level of mercury desorption. Therefore, indicative results should only be used within the context of the tested conditions, and would not be valid if be extrapolated to the full range of conditions that may be observed in the operation of a natural gas transmission line. Consequently it is recommended that further research be conducted on this matter.

8 Conclusions

The TOR studies have brought clarity to the current circumstances regarding mercury in Groningen gas. It has addressed specifics of NAM and GTS locations, as well as domestic consumers. The studies provided the following conclusions.

Before Groningen Gas enters the GTS network, NAM removes ~90% of the mercury content in their sales gas through the deep cooling treatment process at the NAM OVs. In 2013, NAM has increased the amount of mercury removed by decreasing the Deep cooling temperature to -14 °C. This is the maximum reduction of mercury technically possible with the existing NAM facilities. It is anticipated that mercury concentrations at Groningen OVs will not increase in the future if the deep cooling temperature remains at -14 °C.

When sales gas is transported by GTS, the mercury levels decrease as a result of adsorption by the pipeline system. Chapter 7, 'Mercury Behaviour in a Transmission Pipeline', addressed the question whether desorption of mercury in the pipelines could also increase the content of mercury in gas. A test was conducted, with results that showed desorption did not take place in high flow test conditions. However, the answer was not conclusive for low flow test conditions. Nevertheless, the test seems to indicate that desorption is unlikely, or at worst, a very slow process, resulting in a very low increase in mercury content of the natural gas passing through such a pipeline.

The impact on Domestic Users was an important aspect of this report. New measurements showed that traces of mercury (0.3 – 0.7 µg/Nm3 with one outlier of 7 µg/Nm3) are present in Groningen gas supplied to households (KEMA 2013). The exposure model in Chapter 4 put this within the context of health advice for human exposure. The RIVM sets the lifetime exposure limit for mercury in indoor air at 0.05 µg/m3. KEMA tests showed that combustion of gas by domestic users does not expose household to levels of mercury above the exposure limit, assuming homes are free from other sources of mercury. Based on the above, it is concluded that mercury in gas does not expose households to a health risk.

NAM must ensure it complies with legislation covering emissions and environmental conduct. A legal assessment showed that NAM is compliant with the current regulation related to mercury in gas. The concentrations in the gas and current NAM removal practices are compliant with REACH, BAT and minimization principle.

Alternative techniques for Mercury removal were considered. Mercury content may be further reduced by installing filters at NAM or GTS locations. However, following a review of this technique, filter removal is not required for compliance with current BAT. The cost of removing mercury by this technique on a EUR/kg basis was far in excess of reference cases from industry. Filter removal therefore does not qualify as an appropriate technique given the pre-conditions of reasonable cost and cost-effectiveness.

Following this review, NAM and GTS conclude that additional measures for further mercury removal is not necessary at this moment. However, NAM and GTS will continue to cooperate in a mercury monitoring program for Groningen gas. This will include a regular assessment of their compliance within current regulatory requirements. A NAM/ GTS workgroup will prepare an annual report to share results of their mercury monitoring program, to be presented in the TONG meeting. Appropriate action will be initiated if and when required.

9 Appendices

GTS – NAM Kwik beheersing presentation 18 December 2013

NAM - GTS
Kwikbeheersing meet

Minutes GTS – NAM Kwik beheersing meeting 18 December 2013

NAM-GTS mercury in gas meeting 18 decer

Minutes Mercury in gas meeting GTS,NAI

Terms of references (TOR) 2013

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GTS INFORMATIE NORTH- NETHERLANDS 2013

G-gassituatie Noord Nederland.pdf

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