Accurate determination of LNG quality unloaded in Receiving Terminals: An Innovative Approach

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Abstract

In LNG trading, the knowledge of LNG quality or composition is essential to determine LNG Density and Gross Calorific Value, properties necessary to calculate LNG Energy unloaded from ship’s tanks to ground’s tanks in any Receiving Terminal. In this process, the first step is to perform the Sampling & Vaporisation of LNG, which is the most critical point of the LNG quality measurement chain.

Within LNG Custody Transfer field, Enagás has developed and is operating at its Receiving Terminal situated in Cartagena (Spain), an innovative Integral System for Sampling & Vaporisation that links cutting-edge Sampling technology together with Control and Monitoring of parameters and data Processing & Treatment. The result is a reliable, consistent, robust and accuracy System, that allows to guarantee a full representativity of LNG is being transferred and that provides a LNG composition with the best possible accuracy.
1 BACKGROUND

Liquefied Natural Gas (LNG) is natural gas that has been cooled to the point that it condenses to a liquid for shipment and/or storage purposes. LNG is a liquid substance, mixture of light hydrocarbons with Methane as the main component and Nitrogen as inert. It also makes up of a little amount of Ethane, Propane, Butane and Pentane. Minor component concentrations vary with the source of the raw gas, the liquefaction pretreatment, the liquefaction process and the storage conditions.

LNG may be classified taking into account several criteria: Density, Heat Value, Wobbe Index, Methane or Nitrogen amount, etc. Normally, its density is the most usual parameter used for classification. Thus, is spoken of heavy or light LNG’s. Table N° 1 presents three typical LNG qualities due to its density.

LNG is normally stored in cryogenic double-walled tanks at very low temperature, - 160 ºC or – 260 ºF, and at pressure little above atmospheric pressure. Thus, LNG is kept very close to its boiling point. Furthermore, LNG is a cryogenic substance.

The LNG stores in tanks, either ground tank or ship tank, is continuously warmed by any small heat input entering from the surroundings, vaporising it and producing vapour (boil off). As the boiling points of different components of LNG range widely, from -196 ºC to +36 ºC (Figure Nº 1), those constituents that have the lowest boiling points such as nitrogen and methane escape first from the liquid phase into de vapour, changing the initial composition of LNG and its properties.

### Table Nº 1 - Classification of LNG by densities

<table>
<thead>
<tr>
<th>Composition (%)</th>
<th>LNG Light</th>
<th>LNG Medium</th>
<th>LNG Heavy</th>
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<tr>
<td>Methane</td>
<td>98.000</td>
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<td>87.000</td>
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<td>Ethane</td>
<td>1.400</td>
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<tr>
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<td>0.400</td>
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<tr>
<td>Butane</td>
<td>0.100</td>
<td>0.000</td>
<td>0.500</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.100</td>
<td>1.000</td>
<td>0.500</td>
</tr>
</tbody>
</table>

### Table Nº 1 - Classification of LNG by densities

<table>
<thead>
<tr>
<th>Properties</th>
<th>LNG Light</th>
<th>LNG Medium</th>
<th>LNG Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCV[kWh/m³(n)]</td>
<td>11.290</td>
<td>11.650</td>
<td>12.340</td>
</tr>
<tr>
<td>Density [kg/m³(n)]</td>
<td>427.742</td>
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<td>464.831</td>
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<tr>
<td>Density Variation (%)</td>
<td>-</td>
<td>4.2</td>
<td>8.7</td>
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</table>

This phenomenon, known as ageing and not occurring in natural gas phase, increases the content (percentage) of the higher boiling point components (heavy components) in the liquid remaining in the tank, i.e. ethane, propane and other higher hydrocarbons. Consequently, quality and properties of LNG are changing steadily when the time pass (Figure Nº 2).

### Figure Nº 1 - LNG Components Boiling Points

In Receiving Terminals LNG is unloaded from vessels to ground tanks. One of the most important challenges that Operators of the Receiving Terminals must cope with is to determine, as accurate as possible, the quality of LNG transferred from vessel to ground tank. LNG quality is essential to determine the amount of energy transferred for fiscal metering purposes (Custody Transfer). The determination of the energy delivered is not accomplished by a direct method (measure of the energy by a turbine or ultrasonic equipment together with pressure gauges, densimeters and thermometers, for example), but by means of a complex process in where LNG quality (composition) is determined together with the measurement and calculation of some parameters (liquid Volume, liquid Density and Heat Value). Later, by mathematical calculations, energy delivered is calculated. This procedure is always performed during LNG unloading.
The knowledge of LNG quality at any time before unloading helps Receiving Terminals Operators to take, in advance, actions to prevent stratifications and, as a consequence, roll over. Prediction of LNG composition allows also knowing whether quality of LNG, to be unloaded, complies with domestic quality specifications or how far from the limits is. If not, actions should be taken to assure quality commitments. Those actions may range from mixing different qualities into the same tank even adding or removing some amount of specific component. What is more, the cargo could be rejected whether its quality does not comply with domestic specifications.

Enagás, S.A., the Spanish gas transmission company, managing four LNG Receiving Terminals in Spain and conscious of the benefits of the work Innovation–based, has developed and implemented systems and tools that allow to perform routine tasks linked to quality measurement and energy determination in a reliable and accuracy manner.

Figure Nº 2 – LNG Ageing

With reference to the LNG quality measurement, Enagás has designed and implemented an Innovative Integral Sampling & Vaporization System that guarantees that LNG composition provided by the System, is fully representative of the whole LNG transferred. The Integral System provides not only a vapour to be analysed, at regular intervals, by an on line Gas Chromatograph, but that also accomplishes tasks of processing and treatment of the information to give a reliable, robust and accurate LNG composition.
2 INTRODUCTION TO SAMPLING & VAPORISATION

A crucial task that is carried out during unloading process of Liquefied Natural Gas, from tanks’ ship to ground Regasification Plant’s tanks, is to determine the quality or composition of LNG. The knowledge of LNG composition (quality) is essential to calculate properties such as Density and Heat Value. Those properties are required, together with others parameter, to calculate the amount of energy delivered for Custody Transfer purposes.

In order to know LNG quality or composition of the liquid flowing from ship to Regasification Plant through discharge pipe, it is a requisite to take a representative sample of LNG (liquid) and becomes vapour (vaporization). This task is performed by equipment named “Sampling and Vaporization of Liquefied Natural Gas”.

LNG sampling includes three successive operations:
- Taking a representative sample of LNG
- Perform a complete an un-fractionated vaporisation
- Conditioning the vapour sample before transporting it to the Gas Chromatograph

Sampling method is described in ISO 8943:2007 and can be continuous or intermittent. Regardless of type, the LNG sample collected through Sample Probe installed into the LNG transfer line is gasified in the LNG Sample Vaporizer. Typically, such equipment consists of the following parts:
- Sample Probe
- LNG Sample Vaporizer
- Ancillary Devices (pressure gauges, pressure regulators, thermometers, accumulator, holder, valves, gas sample compressor, etc.)

A short description of the function of the main parts of Sampling and Vaporization is given below:

**Sample Probe:**

Sample Probe is a device inserted into LNG to sample from the transferred line to collect an LNG sample. Normally, Sample probe is installed at a right angle to the axis of the LNG transfer line. The shape of the extreme end of the Sample Probe is not critical and the end may be even a straight tube (Figure Nº 3).
Sample Vaporizer:

Sample Vaporizer is an apparatus to completely gasify LNG taken by Sample Probe collected from LNG transfer line and is, normally, electrical-based although exists others heated by water or others fluids. Present designs are flash-based where the LNG goes from liquid to gas without crossing two phases region.

After gasifying LNG, the vapour is taken continuously through the sampling tube to the Sampling Conditioning Unit before entering to Gas Chromatograph for analysis.

Ancillary Devices:

Ancillary Devices allow measuring and controlling some parameters and checking whether the Equipment is working properly. They also allow stabilising, adsorbing pressure pulsations, homogenising and boosting LNG gasified to feed Gas Chromatograph.

For the determination of the composition of the gas sample, by independent Laboratories, in case of dispute, LNG vapour sampling is also collected, at regular intervals, in Samplers Containers (cylinders).

The sampling period for LNG Custody Transfer shall be only that period of time during which the flow rate is sufficient stable, which excludes the initial start-up in the flow rate and the decreased flow rate before stopping.

The LNG sampling shall be carried out continuously during the sampling period at a constant LNG transfer flow rate. In case of a sudden change in the flow rate or in the pressure in the LNG transfer line during sampling period due to, for example, a cargo pump being tripped or an emergency shut-off device being activated, sampling shall be temporally suspended until the flow rate of LNG is normalised (Figure Nº 4).

Figure Nº 4 – Sampling period
3 CHALLENGES IN SAMPLING & VAPORISATION

Sampling is the most critical point of the LNG measurement chain. Every step must always be taken without changing its composition. This is by far the most complicated phase of the measurements and most problems observed in determination of the energy unloaded come from the Sampling system.

In the LNG Sample Probe or Transfer Line, any small heat input or pressure variation may produce LNG partial evaporation, since LNG exists in a state close to its Boiling Point (≈ -164 ºC) and there is big difference among Boiling Points of its components. If that happens, the collected LNG sample that goes to vaporiser could be not representative of LNG unloaded due to a preferential vaporisation.

For this reason, extreme precautions shall be taken so that the collected LNG sample is representative of the transferred LNG.

There are two points in LNG Sampling where extreme precautions must be taken:

- **Sample Probe.** Sample Probe must be located at points where LNG is in a sub-cooled condition. The degree of sub-cooling at a sampling point shall be ascertained by measuring of the temperature and pressure at that point, and comparing the measured temperature with the boiling point of the LNG at the same pressure as calculated from the composition of the LNG.

- **Sample Pipe.** Precautions must be taken to be sure that the LNG remains sub-cooling when is withdrawn through the pipe from Sample Probe to LNG Sample Vaporizer. This is guaranteed with a good thermal insulation of the pipe, constructing the pipe in a way that its length is as short as possible and has the smallest possible diameter (Figure Nº 5).
Another point where special attention also must be taken is the Vaporiser itself.

- **LNG Sample Vaporizer.** The heat capacity of the LNG Sample Vaporizer or the method of vaporisation shall be sufficient to gasify the whole volume of LNG that is being withdrawn for sampling (Figure Nº 6).

**4 ENAGAS APPROACH**

In LNG Sampling & Vaporisation for gas analysis two questions arise: How to be sure that does not exist previous vaporisation and the LNG sample is representative of LNG flowing throughout transfer line? and, is the vaporiser working properly?

Since there are no reference sites to allow sampler evaluation or any viable in-service proving techniques, the only way to guarantee the correct working of such systems is to add extra instrumentation to control, monitor and measure continuously some parameters. In this way and while the values shown lay inside established ranges, can be demonstrated by means of thermodynamics laws, that both the LNG going to vaporiser and the vapour produce by it are representative of LNG transferred.

Moreover, the use of a tailored software application, statistical-basis, dealing with data information collected by a Control Unit from field instrumentation, shall provide a LNG quality-composition statistically robust, reliable and with best possible accuracy.

To achieve those objectives and to guarantee a full representativity of the LNG is to become vapour of the LNG transferred, Enagás has designed and implemented in its Receiving Terminal in Cartagena (Spain) and Integral Sampling & Vaporization System.

The Integral System, installed on the 140.000 m$^3$ jetty, makes up of the following items:

- **Sample Probe**
  Device inserted into the LNG line to sample from LNG transfer line to collect a LNG sample.

- **Sample Vaporizer**
  Device to gasify continuously and completely LNG sample collected by Sample Probe from transfer line.

- **Ancillary equipments**
  Devices such as flow meters, valves, accumulators, gauges, gas compressor, cylinders, etc. essentials to maintain sample homogenous, absorb pressure pulsations, filling cylinders, etc.

- **Devices**
  Gauges to measure special parameters such as pressure, temperature and flow, that allow to check whether the data information are valid or not.

- **Sample Conditioning**
  A set of fittings, valves, flow meters, etc. that condition the sample that is to analyse by the Gas Chromatograph.
• **Online Gas Chromatograph**
  Gas Chromatograph directly connected to vaporiser outlet to perform continuously analysis during unloading process.

• **Remote Unit**
  Electronic device to collect electrical signals from measuring instruments and Gas Chromatograph as well.

In addition, the Integral System consists also of dedicated software that runs the following Settings and Applications:

• **Setting Alarms**
  Data Base with limits of parameters. Outside of them, the values are not acceptable and therefore, LNG composition analysed at this moment is not taking into account for later processing and treatment.

• **Application for Communication**
  Computer programmes to Communicate with Remote Unit, performing also tasks of Data Acquisition, Visualisation and Storage.

• **Application for Alarms**
  Computer programs performing continuously checks to verify whether some parameters lay in or out of preset limits.

• **Application for Processing & Treatment**
  Computer programmes performing Statistical calculations together with Processing and Data Treatment.

With this approach, it is guaranteed that the LNG quality provided by the Integral System is completely representative of the whole LNG unloaded from the ship.

Since from the LNG quality are calculated LNG properties such as Density and Heat Value, basics properties to calculate LNG Energy, it is demonstrated that the Integral System helps to calculate Energy unloaded with the best accuracy as possible.

5 INTEGRAL SYSTEM PRINCIPLE

Integral System intends to guarantee that LNG is sampled and carried to Vaporiser in liquid phase. The Vaporiser vaporises the whole LNG without partial evaporation and the vapour goes into the on line Gas Chromatograph is suitable conditions. Moreover, information given by Gas Chromatograph is treated and processed to provided a robust, reliable a accuracy result (Figure Nº 7).

**Sample Point**

At sample Point, Integral System guarantees that LNG is in liquid state by knowing the LNG behaviour. By thermodynamic laws and as long as the substance lays on the left of the equilibrium liquid-vapour curve, we can assure that the whole LNG is in liquid state. As an example Figure Nº 8 shows the equilibrium liquid-gas curve for LNG Qatar type. A zoom of the zone where LNG normally is at normal condition during transfer process is also shown.

**Figure Nº 7 - Integral System Principle**
Measuring pressure and temperature in transfer line and knowing LNG quality, we can guarantee that LNG is taken in liquid state at sub-cooled condition by Sample Probe.

In this way the values of the devices installed in the transfer line, Integral System allow to guarantee that LNG taken by Sample Probe does not contain bubbles or does not exist previous vaporisation before entering into vaporiser.

**Sample Pipe**

Along the sample pipe, LNG is carried from the transfer line to vaporizer. Any small input heat may cause partial evaporation of the liquid before reaching the vaporiser. To avoid that, an excellent thermal insulation of the pipe (preferable by vacuum) together with a suitable design, both in diameter and length, minimises the undesirable effect.

Moreover, previous calculations made during the design phase of the Sample Probe, taking into account the worst LNG quality to be unloaded, concerning partial vaporisation, allow to state that the warming of LNG due to the input heat keeps LNG even in sub-cooled condition.

During unloading period sample is taken at point A of the Figure Nº 9, just in the middle of the transfer line. As it is said before, LNG is at sub-cooled condition, so there is not any vapour and the whole substance is in liquid state. Through sample line, LNG suffers a pressure drop together with a warming due to heat absorption, so its state changes from point A to point B. If the Enthalpy increase is less than sub-cooling degree, the LNG will still remain in liquid state. Therefore, knowing operation conditions, pressure and temperature as well as LNG quality, we can estimate whether the equilibrium liquid-vapour and limits for those parameters.

*Figure Nº 8 – Natural gas Equilibrium liquid-vapour curve*
It is demonstrated that by means of measuring of parameters of LNG, such as flow, pressure and temperature, and setting ranges of acceptable values, is possible to guarantee that LNG flowing from Sample Point through Sample Line just to Vaporiser inlet, is at sub-cooled condition, therefore it has not had partial evaporation before vaporisation and the LNG is full representative of LNG transferred.

In conclusion, in LNG sampling a correct design of the Sample Probe together with a continuous checking of crucial parameters that control LNG conditions, allow to guarantee that LNG comes to Vaporiser at sub-cooled condition without suffering partial evaporation and, therefore, the sample to be vaporised is full representative of the LNG is about transferred along transfer line from ship to ground tank of the Receiving Terminal.

Figure Nº 9 – Diagram pressure - enthalpy for LNG
Vaporiser

In the Vaporiser, LNG changes of state, from liquid to vapour. The vaporisation of the LNG must be as complete as possible so that the gas obtained is representative of the quality of the LNG transferred. The LNG sample has to be totally vaporised before being sent to the online Gas Chromatograph. In particular heavy components of the LNG shall not remain in the vaporiser.

Figure Nº 10 shows the pressure / temperature diagram for a LNG. The objective is transform LNG from liquid to gas state in supercritical conditions at very high pressure (above 75 bar), thus the LNG sample goes directly into the desired gas state. Such transformation is represented in the figure by the dotted line.

In this way, a good design in order to avoid fractionation, together with measuring some parameters allow to guarantee that the Vaporiser is working properly and the whole LNG that is feeding it is completely vaporised without partial evaporation. In short, not fractioned vaporisation is taking place in the vaporiser, ensuring that the required sample quality and stability is maintained carefully before sending to gas Chromatograph.

Figure Nº 10 – LNG vaporisation path
In that figure, Cricondenbar and Cricondentherm represent, respectively, the maximum pressure point and temperature point at which the LNG exists in two phases.

Within the Sample Probe and Vaporiser, the following operations are taking place (Figure Nº 11):

- The temperature rises from –160 ºC to –150 ºC in the capillary tube approximately at LNG transfer pressure (Point 1).
- Just at the inlet of Vaporiser a pressure reductor / check valve allows LNG flashes (Point 2).
- The LNG vaporisation increases the temperature and pressure and leads them to 80 bar and –100 ºC respectively.
- The temperature is controlled to obtain 55 ºC at the outlet of Vaporiser (Point 3).

To guarantee that, it is essential to install some devices to measure continuously control parameters and check that they lay inside the specified limits. In this case, measuring inlet temperature vaporiser, electrical power, outlet temperature and vapour flow is enough to control the process.

- Inlet temperature guarantees that liquid coming is flashed
- Outlet temperature guarantees that vapour going out the Vaporiser is sufficient warming to analysis
- Electrical power guarantees that vaporiser is at right power
- Vapour flow guarantees LNG flow to be vaporised is enough

Figure Nº 11 –Vaporiser principle
Once the vapour has gone the Vaporiser, a Sample Conditioning Unit is necessary to condition the sample for analysis by Gas Chromatograph. Gas Chromatograph analyses routinely the sample coming from vaporiser providing a set of LNG composition data.

**Operating parameters**

Operating parameters are essentials to assure that Integral System is working properly and check whether the data are valid or not in the processing and treatment process.

Table N° 2 lists the most significant parameters, the type of parameter (control or alarm) as well as the limits admitted.
Table № 2 – Operating Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Point Pressure (PT1)</td>
<td>&gt;1.5 barg</td>
<td>Sub-cooling degree</td>
</tr>
<tr>
<td>Vacuum Pressure (PAL2)</td>
<td>&lt;0.05 barA</td>
<td>Vacuum Insulation (Sub-cooling degree)</td>
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<tr>
<td>Inlet Vaporizer Temperature (TT2)</td>
<td>&lt;-80ºC</td>
<td>Sub-cooling degree</td>
</tr>
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<td>Indoor Vaporizer Temperature (TT3)</td>
<td>65ºC (Set Point)</td>
<td>- Flash vaporization</td>
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<td></td>
<td></td>
<td>- Minimum outlet temperature</td>
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<tr>
<td>Outlet Vaporizer Temperature (TT5)</td>
<td>&gt;20ºC</td>
<td>To avoid condensates</td>
</tr>
<tr>
<td>Vaporized LNG Flow Rate (FIC1)</td>
<td>800-1.200 l(n)/h</td>
<td>- Sub-cooling degree</td>
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<tr>
<td></td>
<td></td>
<td>- Flash vaporization</td>
</tr>
</tbody>
</table>

Alarms

Alarms are controls checked continuously during unloading process. Application for Alarms is the software in charge of checking during unloading period whether the values of the parameters are inside or outside of the preset limits. In case of some parameter is outside of the set range, LNG composition provided by the Gas Chromatograph shall not be taken into account for processing.

In summary, it has been demonstrated that a correct design of Sample Probe and Vaporiser together with a continuous check of crucial parameter allow to assure that:

- LNG Sample is representative of LNG is being transferred
- LNG vapour is representative of LNG Sample

Therefore, vapour that is to analyse is representative of LNG is being unloaded.

Processing & Treatment

After unloading process is necessary to present an Analysis Report. Points to be filled in Analysis Report are described in Custody Transfer handbook. One of the most important points is the LNG quality or composition.

In order to state a LNG composition, representative of all LNG unloaded, is necessary to scrutiny carefully the information provided by Gas Chromatography.
Nowadays, the present Gas Chromatographs (GC) analyse every few minutes the sample that is being sent out by the Vaporiser. So, at the end of the unloading process a set of data LNG composition—raw data—are normally available, as it shows in the Table Nº 3.

Although GC analyses routinely during the period of unloading, may happen that some data are not representative of LNG unloaded due to several circumstances. In those cases data must be considered as not valid and must be taken out of the Table to obtain another set of data—valid data—as is shown in Table Nº 4.
<table>
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<th>Date</th>
<th>Methane</th>
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Mean: 92.364 4.907 2.225 0.278 0.201 0.002 0.000 0.000 0.023
Repeatability (%): 0.08
GCV [kWh/m^3(n)]: 11.993

Application for Alarms together with Setting Alarms Data Base are the responsible for looking into raw data and check if a datum is valid or not, depending on whether the alarm, in the time when the analysis has been performed, was on or off. In others words whether a crucial parameter was inside or outside of the preset limits.

Once raw data has been processed and obtained valid data, it should be convenient to perform some kind of statistical treatment to reject some data that could be consider as an outsider and not representative of the whole. The result obtained applying this approach is robust, reliable and statistically consistent. The result is shown in Table Nº 5. Graphs included just below the tables show remain data for treatment.
Enagás has chosen to perform the task of the Grubbs test. Grubbs test is considered as one of the most useful and known test to take out data that could be considered inconsistent, wrong data, etc. in data treatment. Application for Processing & Treatments is in charge of doing such task. Data set remained—accepted data—is suitable for doing average calculation giving, at the end of the process, a LNG composition (quality) that can be considered as the best representative of the whole LNG unloaded.

6 RESULTS

Enagás’ Integral Systems was commissioned in September 2008. Since then, more than forty (40) unloadings have taken place at its site, on the 140.000 m$^3$ jetty in the Receiving Terminal situated in Cartagena (Spain).

Results obtained during the unloadings have demonstrated that the Integral System is reliable and stable. Figure N° 12 given below shows the results obtained during a case study. This case study has been specially chosen due to the fluctuations in the flow rate in the transferred line (yellow line) occurred during unloading process. As can be observed, even in case of small fluctuations, the Sampling and Vaporisation remain stable.

In the example, we can observe that 80 are the data raw. After processing the number has low up to 60, due to some have been taken out because setting parameters were out of the preset limits. Grubbs test, in the end of the treatment, has eliminated two more. So, 57 data have been chosen as accepted data for subsequent average.
Another feature to be outlined is the performance of the tailored software. With this kind of software, any parameter can be plotted and analysed. Furthermore, we can study the influence among parameters and find out their relationships if any. In this way, if something is wrong, we may study the causes.

7 UNCERTAINTY

Integral System presents lower uncertainty than those former equipments normally used in LNG Sampling & Vaporisation.

The main reasons we can point out are:

- Better design both Sample Probe & Vaporiser
- Better isolation
- More instrumentation
- Continuous Monitoring, Control and Checking of parameters
- Data Processing & Treatment

Although it is not the scope of the paper to show the relationship between uncertainty and repeatability, for cases of LNG unloading it can demonstrate that, roughly, the uncertainty is the double that the repeatability.

Repeatability is defined as follows:

$$\text{Repeatability} (%) = \frac{2.8 \cdot \sigma}{\bar{x}} \cdot 100$$

Where:

$\bar{x}$: Mean value

$\sigma$: Standard deviation

Table Nº 6 shows a set of repeatabilities obtained during the period that Integral System has been working. It can be pointed out that:

- Average repeatability as low as 0,10%
- Average uncertainty as low as 0,20%
- Uncertainty in Sampling & Vaporisation accepted by Custody Transfer 0,30%
Therefore, we can conclude that an Integral System such as is operating Enagás improves by 40% the uncertainty of measure of the LNG quality discharged in a Receiving Terminal.

As uncertainty in Sampling & Vaporisation contributes to overall uncertainty of the calculation of Gross Calorific Value, Integral System helps also to reduce the uncertainty in the chain of measurement of Energy unloaded.

Table Nº 6 – Repeatability with different LNG’s qualities

8 ENERGY DETERMINATION

Roughly, energy (E) unloaded is a function of the difference of levels, in the ground tank, at the beginning and at the end of the unloading (ΔL); LNG temperature; LNG Density (D) and LNG Gross Calorific Value (GCV).

Thus,

\[ E = F (\Delta L, T, D, GCV) \]

As Density and Gross Calorific Value depend also on LNG composition (%)

\[ D = G (\%) \text{ and } GCV = H (\%) \]

In the end,

\[ E = I (\Delta L, T, \%) \]

Since Gas Chromatograph analyses the vapour that is being sent out by Sampling & Vaporisation system, bad vaporisation or any trouble or malfunction of the equipment affects directly in LNG analysis result and, hence, to its properties.

Therefore, LNG Sampling & Vaporisation is strongly related to the accuracy of the Energy determination in Custody Transfer. The more Sampling & Vaporisation is, the more Energy accuracy gets.

Consequently, Integral System helps to reduce the uncertainty in the LNG Energy measurement chain.

9 CONCLUSIONS

As it has been demonstrated, the Integral System meets with the requirements of taking a sample of liquid at sub-cooled state and vaporises it without partial vaporisation. In consequence the sample is representative of LNG is being transferred from LNG carrier to storage facilities.
Moreover, Integral System is able to check and monitor a set of parameters that control the Sampling & Vaporisation process, as well as to perform, subsequently, a statistical scrutiny of data provided by Gas Chromatograph. In the end, a LNG composition fully representative of LNG that is transferred is given.

In conclusion, an Integral System as Enagás is operating, allows LNG Receiving Terminals to guarantee that:

- Mean composition of LNG is given with the best possible accuracy.
- Key parameters – Gross Calorific Value and Density – can be obtained with the best possible accuracy.
- Energy transferred can be calculated with the less possible uncertainty.

10 BIBLIOGRAPHY

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