Raman method for custody transfer measurements of LNG

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Abstract

During the past several years, the European Gas Research Group (GERG) has undertaken a project to evaluate Raman spectroscopy as an alternative to traditional gas chromatography/ vaporizer systems to measure the composition of liquefied natural gas (LNG) for contractual and fiscal metering. Through the use of a cryogenic fiber-optically coupled Raman optical probe, measurements of LNG are made directly in the liquid phase, reducing the complexity of the LNG monitoring system. This paper provides background on the Raman technique and hardware used for LNG measurements, development of the LNG model using certified LNG reference standard samples, field validation data from an installation at the Fluxys terminals LNG discharge line, final results and conclusions of the GERG evaluation project, and exemplary results for field installations at LNG satellite and peak shaving sites and on LNG bunkering vessels.

Introduction

As the world moves toward the reduction of greenhouse gas (GHG) emissions, many countries have set goals of carbon neutrality. The Environment Protection Committee of the International Maritime Organization (IMO) adopted draft amendments of the International Convention for the Prevention of Pollution from Ships (MARPOL)) which will introduce technical and operational requirements to reduce the carbon intensity of ships of 5,000 gross metric tons or more. These requirements could be in force by January 2023. The IMO has a target of reducing the carbon intensity of shipping by 40% by 2030 compared to 2008, and halving GHG emission by 2050.[1]

The use of natural gas to replace coal and fuel oils as a primary energy source is seen as one part of the overall global effort to reduce GHG emissions. As evidence of the benefits of clean natural gas, global gas consumption has seen an average growth of 1.5% per year since 2010 and 2.3% in 2019. To support the trade and economic transport of large quantities of natural gas around the world, there has been a concomitant increase in the demand for liquefied natural gas (LNG), with global LNG trade growing by 13% in 2019. Global liquefaction capacity increased by an average of 6%, and global regasification capacity increased by an average of 5% since 2010. While 2020 and 2021 experienced a drop in LNG demand due in part to the ongoing pandemic situation, market demand is expected to pick up pace again in the coming years. More LNG facilities are being built around the globe, with 2019 being a record year in terms of the number of final investment decisions (FIDs) taken, and there are more inland regasification terminals and floating storage regasification units (FSRUs) being built to manage the energy demand.[2]

Commercial trade of LNG

The sale and purchase of LNG during large scale transfers at baseload liquefaction or regasification terminals, or for small scale transfers associated with truck loading or bunkering activities, is a custody transfer usually based on a contractual agreement. The value of the transaction is most often based on a measurement of the total energy transferred between the two parties. The GIIGNL LNG Custody Transfer Handbook[3] (CTH) is widely accepted as a reference document that defines how the total energy transferred should be calculated, and provides the following formula for calculating the energy of the transferred LNG:

$$E = V_{LNG} \times D_{LNG} \times GCV_{LNG} - E_{gas\ displaced} - E_{gas\ consumed}$$

V_{LNG} is the volume in m^3, D_{LNG} is the density in kg/m^3, and GCV_{LNG} is the gross calorific value in MMBtu/kg. Corrections are also made for the net energy of the displaced gas during the transfer ($E_{gas\ displaced}$) and the energy of any of the gas consumed by the ship during transport or offloading ($E_{gas\ consumed}$), which may either be measured, or agreed upon by both parties to estimate these as fixed quantities. A critical element in this calculation involves the precise measurement of the composition of LNG to calculate the gross calorific value (GCV) of the LNG cargo.

Measuring LNG composition by gas chromatography

Conventional LNG terminals use collecting retained samples, often in combination with a gas chromatograph (GC), to measure LNG composition using a sample handling arrangement that includes an LNG vaporizer and an automatic sampler compliant to requirements stated in ISO 8943. The vaporization of LNG has always been challenging, as the LNG transferred is close to boiling point, with a preferential boil off risk for lighter components. These conditions mean that an LNG vaporizer operates in a narrow operating window where a change in LNG flow, pressure or temperature can impact the vaporizer performance. To prevent these risks from impacting the measurement uncertainty, it is essential to prevent partial and pre-vaporization of the LNG sample. Careful design, installation, and proper maintenance is required to ensure good insulation and the elimination of hot spots in the sample vaporization and transport paths. Improper or incomplete vaporization is usually the dominant source of uncertainty in the measurement of LNG composition,[4] which translates to added uncertainty in the energy content transferred.

As a result of that, LNG vaporizer systems can require considerable stabilization time after start-up, as well as stable flow and pressure to be able to produce precise measurements. These delays, which can be greater than 30 minutes, depending on the specifics of the installation, primarily impact small LNG cargo transfers common in bunkering and truck loading, where total cargo transfer times can range from 30 minutes to a couple of hours, and for which LNG transport lines are typically emptied between transactions.

Raman spectroscopy for LNG measurements

In recent years, Raman spectroscopy has been identified as a promising technology to determine the LNG composition directly in the cryogenic process liquid. Raman spectroscopy has been used for nearly a century to provide chemical identification and composition information for gaseous and condensed phase mixtures. In a Raman measurement, laser light interacts with molecular vibrations of the sample components, with some of the incident light losing discrete amounts of energy to different vibrational modes in the each of the types of molecules in the sample. This Raman scattered light has less energy than the incident laser light. When lasers with visible wavelength emission are used, each Raman band has a different color than the original laser light and each different type of molecule generates one or more colors that are unique to that molecule.

Endress+Hauser Raman analyzers for LNG analysis typically use lasers in the visible and short-wave near-infrared region, which are compatible with transmission along low-cost fiberoptic cables, allowing fiber-coupled Raman probes to be used to measure the LNG hundreds of meters from the analyzer. The Raman light is collected by the fiber probe at the point of measurement and is transported back to the analyzer along the fiberoptic cable, eliminating the sample lag times inherent in heated gas sample transport lines. As an in-situ measurement, no potentially explosive gases are removed from the pipe at the sample tap location, nor transported to the analyzer, greatly enhancing the safety of analyzer operators and service technicians.

Figure 1 shows the typical layout of a Raman analyzer installation, consisting of a base unit that contains the laser source, electronics and power supplies, detection module, and an embedded or an external controller. The Raman probe can be located up to 500 metres from the base unit. The base unit is coupled to the probe using hardened, crush-resistant fiber optic cables capable of being routed via conduit or cable trays, using robust industrial electro-optic connectors.

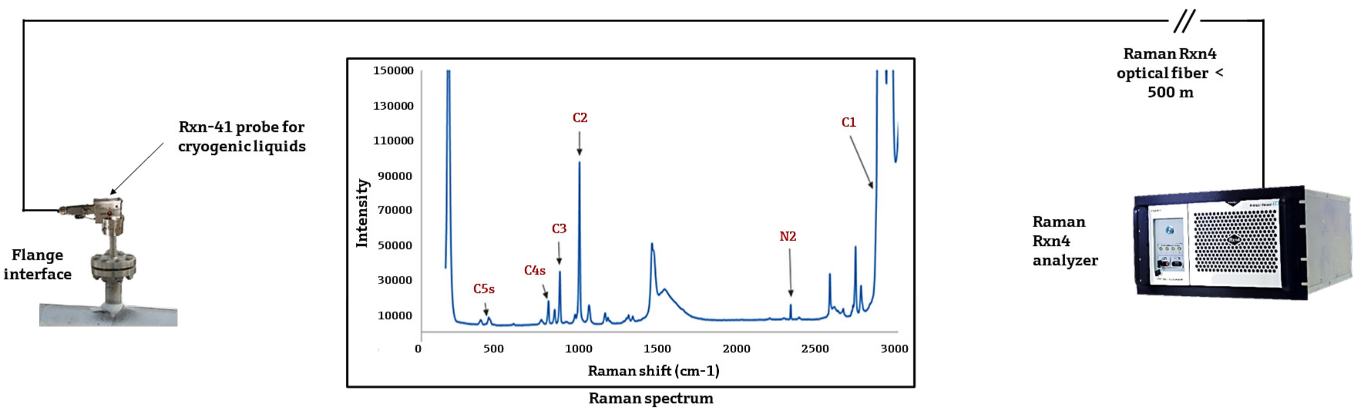


Figure 1: Typical installation of a Raman Rxn4 analyzer for LNG custody transfer measurements consisting of a base unit, a fiber optic cable, and a Raman immersion probe.

(a) (b)

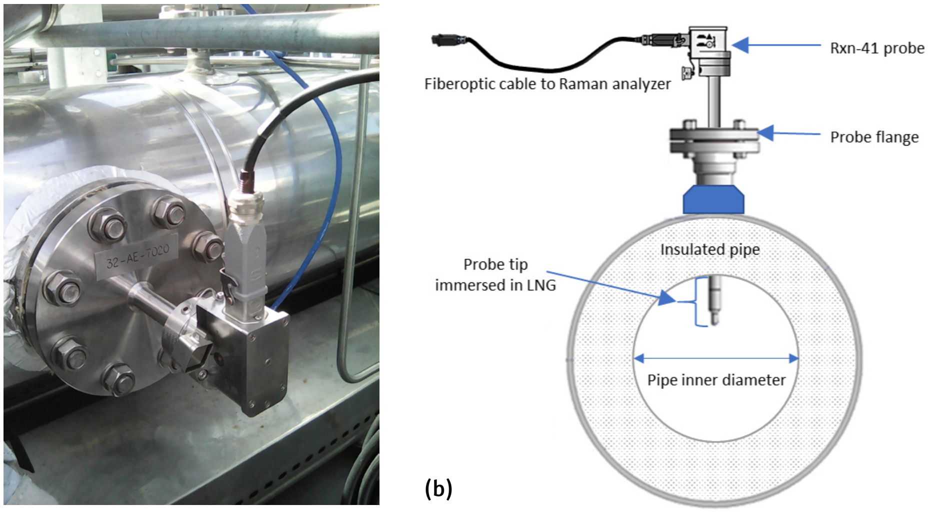


Figure 2: (a) An Rxn-41 cryogenic probe installed on the main LNG transfer line from an LNG bunker ship; **(b)** cross-section of the probe, showing the direct flange mount of the Rxn-41 probe and the immersion of the tip of the probe into the flowing LNG stream.

For the analysis of LNG, an Endress+Hauser Rxn-41 immersion probe compatible with cryogenic fluids is inserted directly into the LNG sample, either in the main transfer line, or in a bypass loop,[5-7] most often using a standard flange mount.

Figure 2 shows a typical direct flange mounting geometry typically used for the loading and unloading line of a bunker barge. The cut-away shows how the probe passes through the access flange and the pipe insulation layer, and into the main transfer line, so that it is in direct contact with LNG. Both vertical and horizontal installation geometries can be used, with the horizontal geometry shown in Figure 2(a) being the most deployed. Turbulent flow conditions dominate LNG bunkering flow dynamics, so LNG stratification is uncommon, and the Raman system will provide accurate results whenever the probe is immersed in the flowing LNG. Recommended installation geometry is for the probe tip to be inserted three inches into the flowing liquid, or no more than half of the pipe diameter, whichever is shorter, to ensure that the probe is always immersed in LNG when measurements are required and that the probe can withstand the forces of the flowing fluid.

Raman analyzer evaluation for LNG custody transfer

During initial consideration of the potential to use Raman analysis for the measurement of LNG in the liquid phase, it became clear that certified reference LNG samples were needed with different compositions representing LNG traded worldwide. Effectech, a provider of inspection, calibration, and testing, developed the facilities for preparing reference LNG samples from primary reference gas mixtures[8] and appropriate interfaces to that equipment to analyze these reference LNG mixtures in the cryogenic liquid state via Raman spectroscopy[9]. With this capability in place, it became possible to develop a method that is directly traceable to the mole under a procedure accredited by the United Kingdom Accreditation Service (UKAS), which creates the opportunity to consider Raman measurements for custody transfer applications. A project was launched to test the Raman performance in the field at an LNG terminal. The project was started between Shell Global Solutions International, Endress+Hauser, and Fluxys LNG, who was approached to participate in field evaluations. However, to provide maximum transparency to the LNG business, the Groupe Européen de Recherches Gazières (GERG) was also approached to participate in the evaluation.

GERG, and its member organizations help to develop and evaluate innovative projects and products for European gas infrastructure, which includes projects focused on hydrogen, biomethane, infrastructure, and LNG. The GERG group initiated a project entitled *Raman method for determination and measurement of LNG composition*[10] in February of 2017. A GERG steering committee was formed, led by Shell Global Solutions International, with Fluxys LNG maintaining the contact and reporting to the GERG. The following companies participated in the steering group; Enagás, Naturgy, TotalEnergies S.E., GRTgaz RICE, Tokyo Gas Co. Ltd., Equinor and Exelerate Energy.

The objective of the program was to demonstrate the measurement capabilities of Raman technology to provide reliable, accurate and precise composition measurement directly from LNG in the liquid phase. During discussions within the GERG, Fluxys LNG Belgium volunteered to host the Raman field test at their LNG receiving and regasification terminal in Zeebrugge, Belgium.

Figure 3 shows a typical installation of an Rxn-41 probe onto an LNG transfer line, similar to the one installed at the Fluxys terminal. LNG is continuously flowing in the transfer line. The probe is directly inserted into the main flow of LNG such that the tip of the probe is always immersed in the flowing cryogenic fluid. From the jetty, the Raman analyzer take-off location is about 300 metres downstream of the LNG vaporizer utilized to feed gas to the GC used in LNG custody transfer.

Figure 3. An Rxn-41 probe installed on an LNG transfer line similar to the one at the Fluxys LNG terminal.

Prior to the initiating the field testing, and to ensure that the Raman instrument and application were working within the limits, the Raman analyzer fiberoptic cable and measuring probe were sent to the Effectech metrology laboratory for a validation run on a certified LNG standard, prepared under their UKAS accreditation. For this validation, the composition was matched closely to the average LNG composition discharged at Fluxys LNG. Based on results from initial testing at the Fluxys terminal, some modifications were made to the method to account for variation of LNG temperature during the measurement process and between different cargos. Once the final method was completed and verified at Effectech to perform within target specifications, the hardware was sent to the Fluxys terminal for installation and to begin field tests.

The primary goal of the field tests was to determine if Raman technology was able measure the LNG composition and calculate the physical properties for energy calculation at a precision suitable for LNG custody transfer under operational conditions. For this evaluation, the results were compared with the Fluxys LNG custody transfer quality measurement system designed to meet the performance criteria in the GIIGNL Custody Transfer Handbook (V6). Multiple cargos were analyzed at the Fluxys terminal. Table I provides a comparison between both the volumetric and mass-based gross heating value (GHV) for some of the cargos evaluated during the test period. The En method, as defined in ISO 17043, was used for the comparison of the Raman and GC data, with both measurements under test having to meet the mass based GHV uncertainty of 0.07% MV (k=2). No significant bias was found between the results of the tested Raman analyzer and the traditional LNG vaporizer/GC system.

The results shown in Table II show that the Raman analyzer demonstrated improved repeatability on main components and GHV when compared with the vaporizer/GC system used at the Fluxys terminal for LNG loading/ discharge during the evaluation period. Target limits from both the GIIGNL Custody Transfer Handbook (version 6.0) and ASTM D7940-14 are provided for comparison.

En Evaluation between Raman analyser and Fluxsys LNG vaporizer/GC according to ISO 17043												
Test Cargo nr.	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26
GHV_vol	0.19786	0.02242	0.09786	0.04151	0.20608	0.31176	0.24657	0.09437	0.30936	0.45828	0.12012	0.08301
GHV_mass	0.98428	0.54260	0.61301	0.78687	0.71394	0.62491	0.73219	0.28972	0.71575	0.35835	0.09579	0.94408
En Limit	1	1	1	1	1	1	1	1	1	1	1	1

TABLE I. Comparison of volumetric and mass based gross heating values for 12 cargos.

Repeatability performance based at 2 times the pooled standard deviation over all evaluated cargoes												
	Methane mol %	Ethane mol %	Propane mol %	I Butane mol %	N Butane mol %	I Pentane mol %	N Pentane mol %	Nitrogen mol %	GHV_v MJ/m3	GHV_v % MV	GHV_m MJ/kg	GHV_m % MV
Rep. Limig_GIIGNL CTH 6.0										0.2		0.07
Repeatability_GC	0.072	0.056	0.014	0.005	0.005	0.00030	0.0002	0.008	0.029	0.074	0.009	0.016
Rep Limits ASTM D7940-14	0.06	0.06	0.06	0.02	0.02	0.012	0.012	0.02		0.05		
Repeatability_Raman	0.051	0.042	0.009	0.003	0.003	0.00004	0.0016	0.011	0.019	0.048	0.011	0.020

TABLE II. Comparison of the repeatability of the Raman analyzer and vaporizer/GC for each component of the LNG cargos, as well as the calculated heating values.

Although the Raman model meets the accuracy criteria, the standard tools used to perform the optical calibration introduce too much uncertainty for the system to meet the strict custody transfer uncertainty requirement of 0.07% MV for mass based GHV at 95% confidence level, as stated in the GIIGNL Custody Transfer Handbook (V6). This issue can be overcome by performing a verification on a high accuracy certified LNG standard, which in this case was performed at the Effectech UKAS accredited laboratory. Having an additional verification to improve measurement uncertainty of the specific hardware being utilized is a common practice for analyzers used in custody transfer. This practice produces data with a higher level of accuracy for any specific installation versus comparison between multiple analyzers at multiple locations.

The method uncertainty for the Raman analyzer, based on the manufacturers standard practice of using the optical calibration tool is found to be just outside the 0.07%MV performance limit but met the manufacturer's claim of ± 0.112 MJ/m^3 (± 3 Btu/scf), without requiring the additional validation on a certified reference LNG sample.

Key conclusions from the Raman LNG testing project include:

1. A Raman analyzer solution replaces both the LNG vaporizer and the GC. The vaporization of LNG has always been challenging as the LNG transferred is close to boiling point, with a preferential boil off risk for lighter components. To prevent these risks from impacting the measurement accuracy, strict design requirements and maintenance need to be in place.
2. The Raman analyzer demonstrated a much faster response to process changes, making it especially suitable for measuring small and medium sized cargos, where loading lines are not kept under cryogenic conditions outside of loading/discharge operations.
3. The Raman analyzer performance, when verified against a certified high accuracy LNG standard, meets the GIIGNL CTH (version 6.0) performance criteria for LNG custody transfer and measurements were in close agreement with a well-maintained traditional LNG custody transfer measurement.
4. During the runs, the tested Raman analyzer architecture met the target requirement of 99% availability. The Raman system under test showed no drift and performed without alarms or maintenance intervention for the full evaluation period of six months.

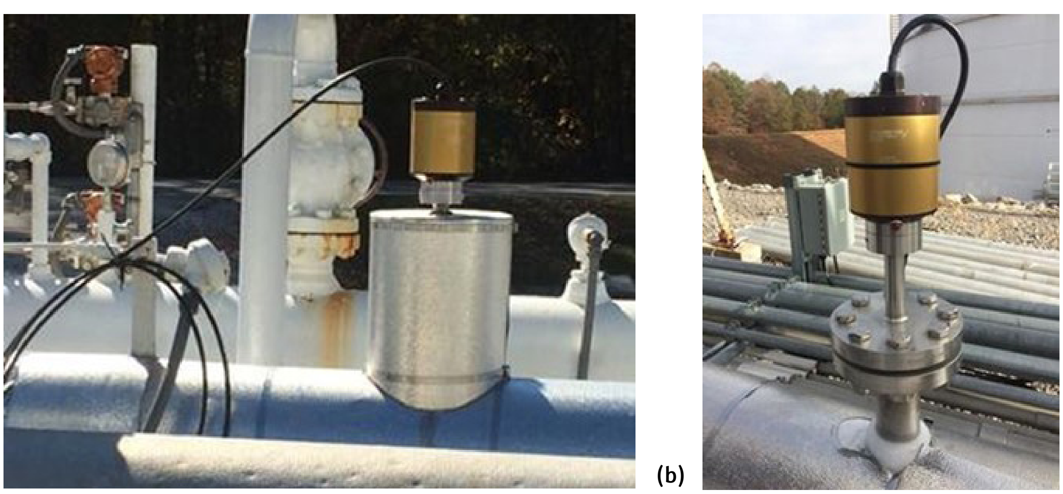
The following data are examples of field installations which illustrate each of the key conclusions from the GERG analyzer evaluation project.

Potential issues from poor quality vaporization

Endress+Hauser Raman LNG analyzers were installed at two small scale LNG facilities in the United States that provide LNG truck loading services in order to monitor the quality of LNG being loaded onto trucks for transport. Figure 3 shows photos of the Rxn-41 probe installation at the two US truck loading sites. The probes are mounted onto flange access points provided by each site and penetrate through the pipe insulation and into the transfer line, as illustrated in Figure 2(b) above.

The first site is a peak shaving LNG facility which has a single LNG storage tank with a capacity of 56,500 m^3. It provides peak-shaving for the local gas grid, as well as limited truck-loading capability, averaging around 5 truck transfers per week. The second site is a satellite facility, used exclusively for truck transportation of LNG, with a storage capacity of 18,200 m^3. In 2016, this site was loading an average of 3 trucks per day, with a peak of 8 trucks per day, with an average transfer of 40 to 60 m^3 per truck. Loading of a single truck takes 30 to 45 minutes for typical LNG transport trucks, and up to 60 minutes for ISO containers. At both sites, LNG vaporization occurs via ambient heating of LNG as it is pumped through a 300-foot length of ¼-inch stainless steel tubing, as opposed to using a commercially available vaporizer. LNG tanker trucks are parked on a scale and weighed before and after being loaded with LNG. LNG quality is also measured, and the results incorporated into the

(a)



(b)

Figure 4: Typical installations of the Rxn-41 probe on LNG transfer lines between the storage tank and truck loading area at **(a)** the first site, a peak shaving LNG facility, and at **(b)** the second site, a satellite LNG facility.

transfer documentation. During the initial evaluation at both sites, LNG was analyzed by both the Raman instrument and a vaporizer/GC system.

Figure 4 illustrates some of the potential problems that can occur during LNG transfer, particularly when the vaporization is not tightly controlled and maintained. Figure 4(a) shows the calculated Btu/scf values for both the installed vaporizer/GC and Raman systems during a single LNG transfer event at the peak shaving facility. During the LNG transfer, the flow conditions changed, impacting the vaporizer efficiency. This change resulted in a significant increase in the uncertainty of the Btu values reported by the chromatograph (from a range of ~5 Btu/scf to over 35 Btu/scf, and almost a 6 Btu/scf increase in the average value of the calculated energy content for the last 2/3 of the transfer), making it unusable for custody transfer. The Btu values reported by the Raman analyzer were all within a span of ~1 Btu/scf, and the results were unaffected by the flow event.

Figure 4(b) shows the vaporizer/GC and Raman data for the average energy content of 87 truck load transfers at the satellite facility that occurred over a period of 100 days. All transfers were made from the same storage tank, with the total volume transferred representing approximately 25% of the storage tank capacity. The reported average energy content between transfers varied by almost 24 Btu/scf over the 100-day period of the evaluation. These results illustrate a potential risk of not installing a high-quality vaporizer and not providing the high level of maintenance required to keep the vaporizer operating under optimal conditions. In contrast, the Raman results show the benefits of eliminating vaporization in this installation, providing consistent results over the 100-day period. The Raman analyzer did not require recalibration or maintenance during the test period.

Benefits of fast start-up stabilization times

In addition to the risks associated with partial and pre-vaporization, LNG vaporizer systems usually require considerable stabilization time after start-up and stable flow and pressure to be able to produce precise measurements. These delays, which can be greater than 30 minutes, depending on the specifics of the installation, primarily impact small LNG cargo transfers common in bunkering and truck loading, where total cargo transfer times can range from 30 minutes to a couple of hours, and for LNG transport lines which are typically emptied between transactions.

Figure 6 shows the results obtained comparing a vaporizer/GC and a Raman analyzer installed in an LNG transfer line during a 24-hour period. Stable LNG flow was interrupted about 8 hours into the test and resumed approximately an hour later. Accurate Raman measurements began automatically after the resumption of flow. In this test, the vaporizer/GC system had to be reset and recalibrated, and then required an additional cool-down cycle, resulting in a delay of several hours before stable performance resumed.

Figure 7 shows typical data from a Raman analysis on an LNG bunker ship during a bunker transfer. The plot includes an overlay of the measured flow rate determined by radar, and denotes the ramp up, steady flow, and ramp down of the LNG flow during the bunker transfer. A flow threshold is set above which Raman data from the LNG is used for the preparation of the bunker delivery note.

The data show that the system composition results stabilized rapidly after the introduction of LNG into the pipe, between 7:40 p.m. and 7:50 p.m., and was stable until flow ramp-up was initiated near 8:20 p.m. Note that the measurement performance remains stable even during flow ramp-up and ramp-down, as the Rxn-41 probe measurement is unaffected by varying flow rates. Steady-state flow rate for this bunker ship is ~600 m^3 per hour. Due to the rapid stabilization of the Raman analyzer, the bunker ship set the threshold for acceptance of the Raman data at just 150 m^3 per hour for both ramp-up and ramp-down.

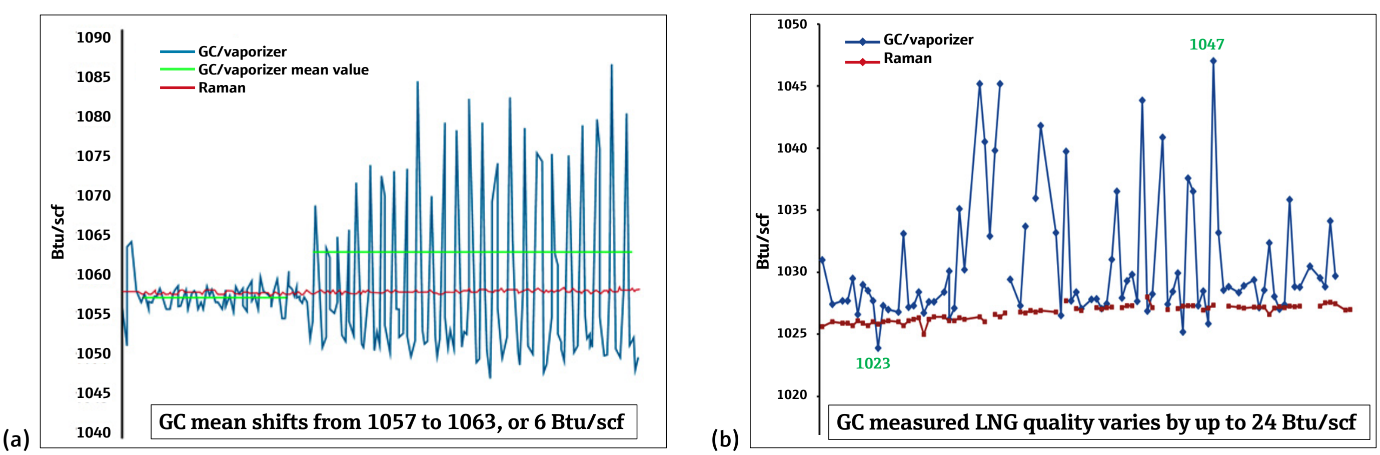


Figure 5: Comparison of vaporizer/GC and Raman LNG energy measurements for **(a)** a single LNG storage tank to truck transfer at site 1; and **(b)** average measured Btu value for 87 trucks over 100 days at site 2.

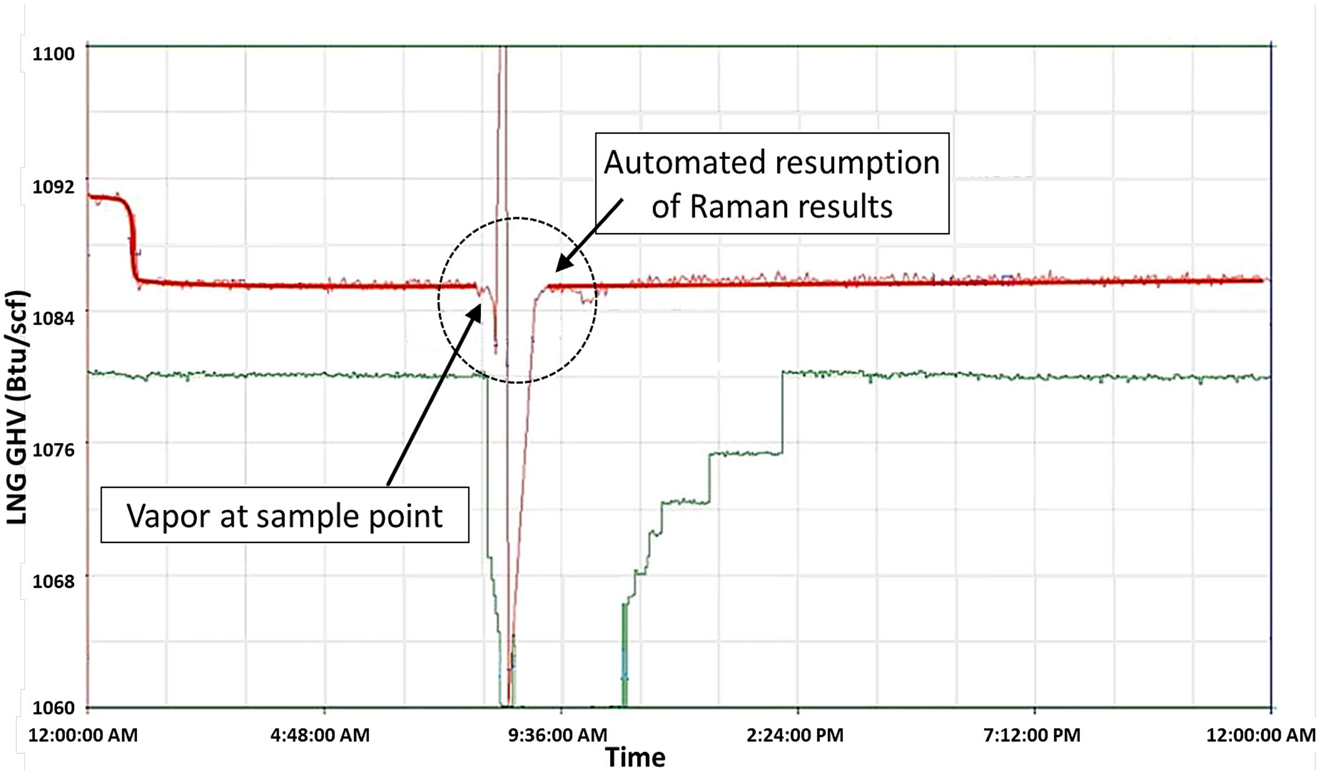


Figure 6:. Comparison of vaporizer/GC and Raman analyzer to flow interruption.

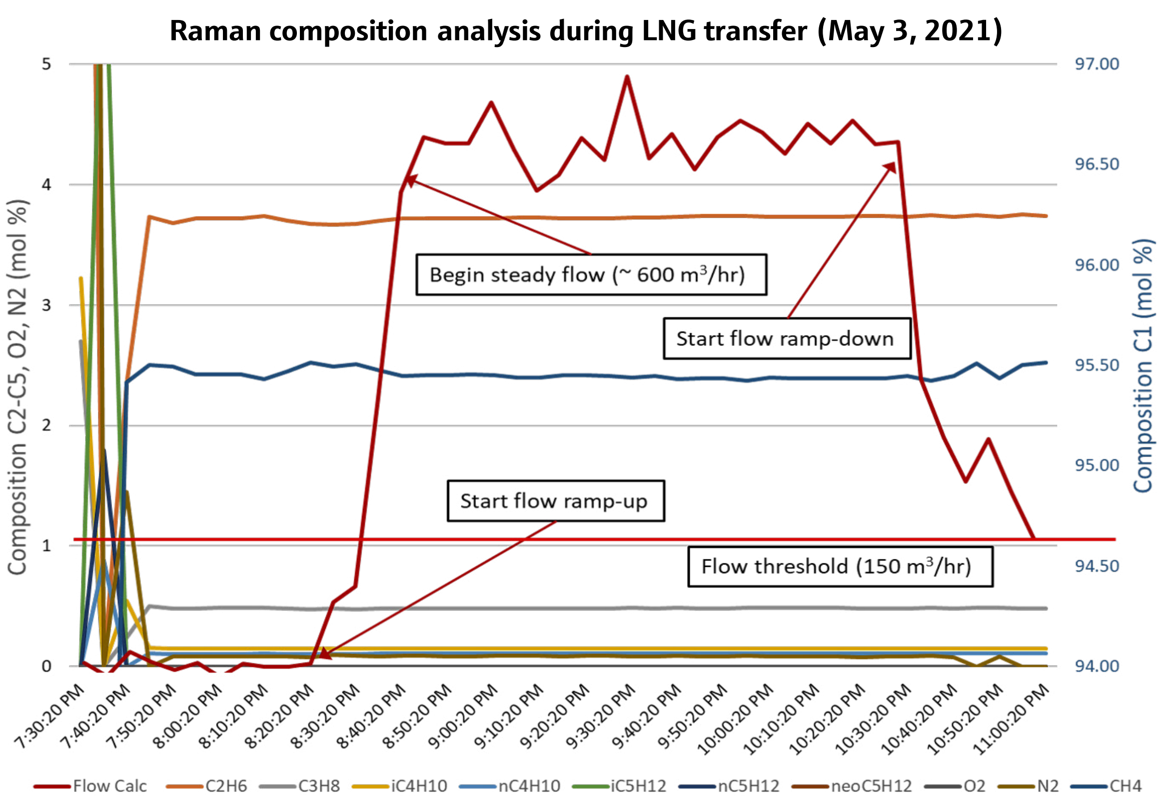


Figure 7: Raman measurement of LNG during flow ramp up, steady state flow, and ramp down.

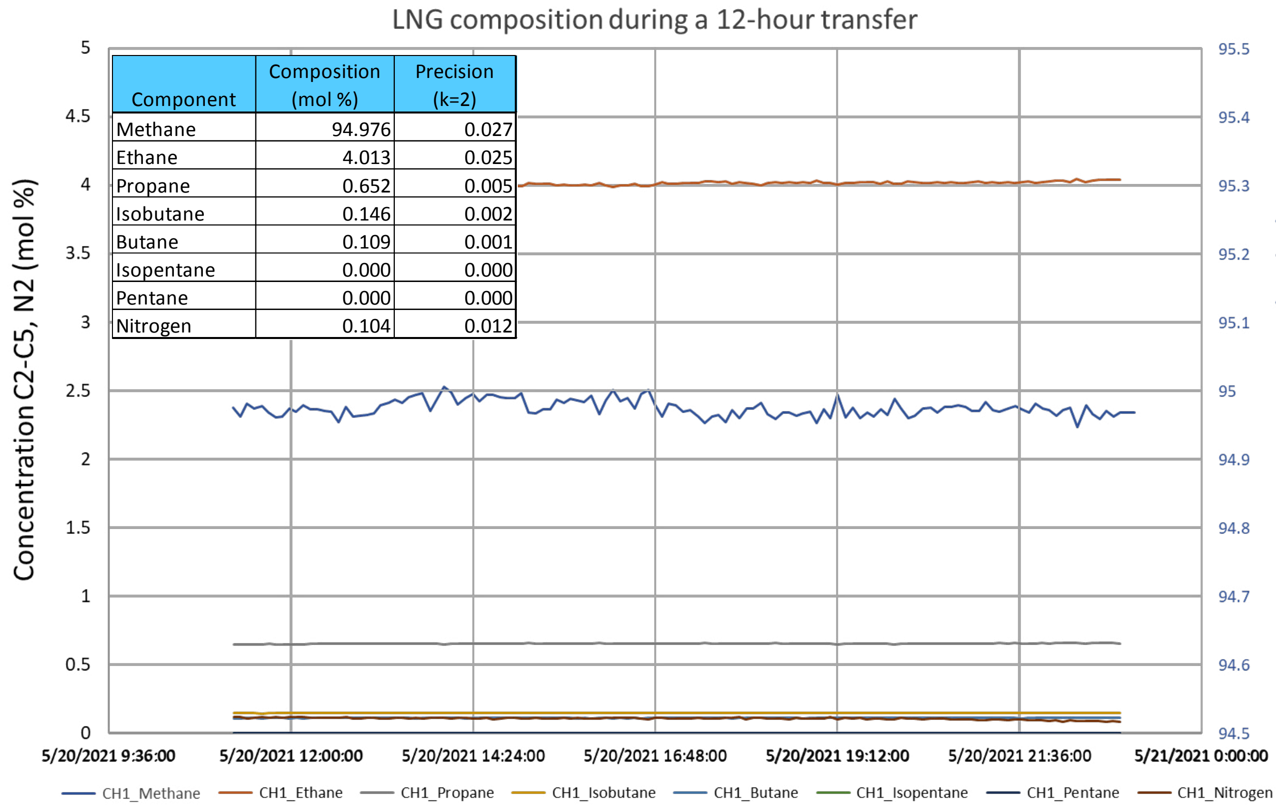


Figure 8: Raman analyzer LNG composition data and the precision for each component during the 12-hour bunker transfer.

Comparing a Raman analyzer and well-maintained vaporizer/GC

An Endress+Hauser Raman analyzer was installed on a large LNG bunkering vessel which is part of the rapidly developing European LNG bunkering market. Initial testing and evaluation involved comparing the results of the Endress+Hauser Raman analyzer with an existing jetty GC system fitted with a vaporizer. Figure 8 shows the Raman analysis results of a 12-hour LNG bunker transfer of LNG, illustrating the stability of the Raman measurement over the complete LNG transfer.

Table III provides a comparison of the Raman measurements to the results using a well-maintained vaporizer/GC system installed at the jetty. The difference between the two measurements for all components is between 10 and 100 parts-per-million, with the exception of nitrogen (700 ppmv), demonstrating that a fielded Raman analyzer can produce equivalent results to this well-maintained vaporizer/GC system without requiring the level of operational expenditure necessary to maintain the top-level performance of the vaporizer system.

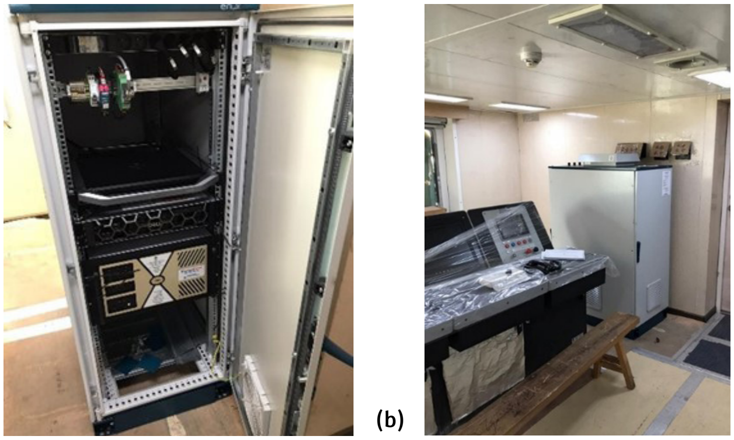
Component	Raman Composition (mol %)	Jetty GC Composition (mol %)	Difference (mol %)
Methane	95.381	95.371	0.010
Ethane	3.737	3.746	0.009
Propane	0.509	0.510	0.001
Isobutane	0.155	0.156	0.001
Butane	0.122	0.122	0.000
Isopentane	0.000	0.000	0.000
Pentane	0.002	0.001	0.002
Nitrogen	0.084	0.014	0.070

TABLE III. Comparison of Raman LNG results with average jetty vaporizer/GC results for an LNG transfer. Typical differences are < 100 ppmv for methane and ethane, and < 10 ppmv for propane through pentane.

Validation of a Raman analyzer for LNG bunkering

In 2019, a Raman LNG analyzer system was installed in the analyzer room of a European LNG bunker using a 19-inch rack mount cabinet, as shown in Figure 9. The Rxn-41 probe was installed in a transfer line on the deck of the ship (as shown in Figure 2(a)) and connected to the analyzer by routing a fiberoptic cable between the probe and the analyzer.

Raman validation trials were performed under the auspices of the global leader in LNG bunkering using data from 15 bunker transfers, with the goal of assessing if the Raman results were of sufficient quality to be used for commercial transactions. The Raman data, along with the loading reports



(a) (b)

Figure 9: (a) Raman Rxn4 analyzer, external display, and keyboard mounted in a 19″ rackmount cabinet on the LNG bunkering ship; **(b)** typical location of the Raman instrument rack in a bunker ship control room.

from the terminal, were analyzed by a world-leading testing and certification company. Bunker transfers ranged from 250 to 1500 m^3. Terminal data and Raman data were compared to simulations of the composition that accounted for the blending of the heel with transferred LNG as well as for composition changes due to ageing of the LNG.

Per the sponsor of this evaluation, the validation trials were performed with exceptional results. Raman analysis of the combined energy content contained in the 15 bunker transfers showed a variation of only 242 MMBtu out of a total of 254,292 MMBtu delivered, within 0.1% of the predicted analysis and the terminal gas chromatography results. The Raman results also accurately showed the expected impact of boil-off/weathering. The sponsor noted several benefits of the Raman analyzer over traditional systems, including the elimination of the vaporizer, calibration, and carrier gases (and storage for the gas cylinders), no physical transfer of gas via insulated lines, no gas exhausted, lower maintenance cost, and no need for the vessel crew to include a laboratory technician.

Summary

Raman measurement is a reliable and accurate alternative to traditional vaporizer/GC systems for measuring the composition and energy content of LNG samples during custody transfer transactions. Extensive testing was performed with reference LNG samples at Effectech and installed at a baseload LNG transfer facility at Fluxys LNG. Raman analyzer performance, as demonstrated by the tested device when verified against a certified high accuracy LNG standard, meets the GIIGNL CTH (version 6.0) performance criteria for LNG custody transfer and produces measurements in close agreement with a well-maintained traditional LNG custody transfer measurement. Results further demonstrated that the Raman analyzer provided equivalent results with one of the best-in-class vaporizers in terms of repeatability.

The results of this evaluation indicate that the uncertainty limits that can be achieved for a well-engineered and maintained vaporizer/GC system can be tighter than that of a Raman analyzer system. However, the required OPEX and technical expertise necessary to outperform the Raman analyzer system is extensive. The Raman analyzer proved to be a reliable instrument, with > 99% uptime during the evaluation and no validations or maintenance were required. The Raman system proved to be more robust to process changes, such as flow rate, and provided a faster response to the extreme process changes due to intermittent flow of cryogenic LNG, which is particularly beneficial for LNG truck loading and bunkering transactions.

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