Gas Transmission
Network Innovation Allowance

nationalgrid

In Pipe NTS Liquid Monitoring Systems

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In-Pipe NTS Liquid Monitoring Systems

Final Report

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1. Introduction

National Grid wishes to improve on current methods for detecting liquids that enter the National Transmission System (NTS). While Gas Chromatographs (GCs) and other gas analysers monitor gas quality, Gas Safety Management Regulations (GS(M)R) require that gas transported in the NTS should not contain liquids or solids. This is not possible to determine with current technology at custody transfer points.

The LineVu camera system brings a new approach to monitoring that provides certainty about gas pipeline contamination levels. Operators are provided with a live view of pipeline activity, and image processing is used to alarm if contamination is present. It is anticipated that implementing this technology will enable compliance with GS(M)R, improve process safety, and have several financial benefits for National Grid.

It is hoped that by continuously monitoring the effectiveness of gas/liquid separators, more effective maintenance will be possible, and the threats posed by contamination will be decreased.

This Final Report document will highlight the progress achieved during this project and how it has met the deliverables set out at the start. Initially, an overview of the overall system will be described to provide a clear understanding of the individual stages undertaken in the project.

2. Document Overview

This document will illustrate the problems that liquid carryover and contamination cause. It will discuss how LineVu works, the results of this project, and how they may impact operations. It will also illustrate the benefit to users of integrating alarms and live video to aid the control of processes and gas acceptance criteria.

3. Project Scope

Significant liquid contamination can result from a gradual build-up of liquid deposits on pipe surfaces, from components that may normally be present in the gas phase. Depending on the specific components involved, dew temperature measurements may not predict the potential liquid deposition. The gas composition may indicate increased concentrations of critical components in the gas phase, but these are not routinely monitored by the Gas Network Control Centre (GNCC).

In general, on the National Transmission System (NTS), all sample points and measuring instruments are designed to sample and analyse dry gas. Any liquid contamination picked up by the sample probe causes damage to the analysers. This issue is further exacerbated by the fact it is not an easy process to remove liquids.

There are no instruments in place to monitor the concentrations of some potential liquid contaminants (glycols and methanol) across the NTS.

4. Project Objectives

A full review of each system (fixed & mobile) will be presented. If the trials prove successful, the systems will be adopted as a business as usual system for liquid monitoring within the NTS. The necessary procurement and National Grid specification/standards, inclusive of standard design templates, will be amended accordingly.

5. Success Criteria

The programme will provide an in-service demonstration of video liquid detection systems for in-pipe monitoring of gas transmission networks. The trial will be conducted at sites of specific interest, and will thus be an effective validation of the video detection system.

6. Compliance with Regulations and Tariffs

Gas quality is determined in GS(M)R in Schedule 3, part 1:

> *"[No person shall convey gas in a network if] it contains solid or liquid material which may interfere with the integrity or operation of pipes or any gas appliance."* [3]

In comparison, a typical interstate Pipeline Tariff in the USA governed by the Federal Energy Rouse Council (FERC):

> *"The gas shall be commercially free from objectionable odors, bacteria, solid matter, dust, gums and gum-forming constituents, free liquids, crude oil, and any other substance that might interfere with the merchantability of the gas, or cause injury to or interference with proper operation of the lines, meters, regulators, compressors, processing plants, or appliances through which it flows."* [4]

Neither regulation quantifies a limit, only that it "may" or "might" interfere with merchantability or cause damage. There is, therefore, no hard limit to the amount of allowable contamination, and no burden of proof that it would cause damage.

The regulatiuons are in place to maintain safety levels in gas networks (see *Section 14.a*). As discussed in *Section 14.b*, current methods of gas analysis, via sampling, do not provide an effective method of continuously monitoring a separator's performance. The industry therefore has a blind reliance that separation systems are performing to their specifications. Studies indicate that real-world separator performance is significantly decreased over time, with one study[10] finding that 16x the filter specification was allowed to pass through a filter system.

The image processing in LineVu can provide the immediate operator feedback necessary to diagnose and rectify separator performance problems, and improve maintenance practices. For National Grid, it provides better certainty regarding the quality of the gas entering the NTS.

It will also detect solid objects (welding rods, washers etc.) entering the NTS that could cause plant damage.

7. The LineVu System

Figure 1. shows the three main components of the fixed LineVu system:

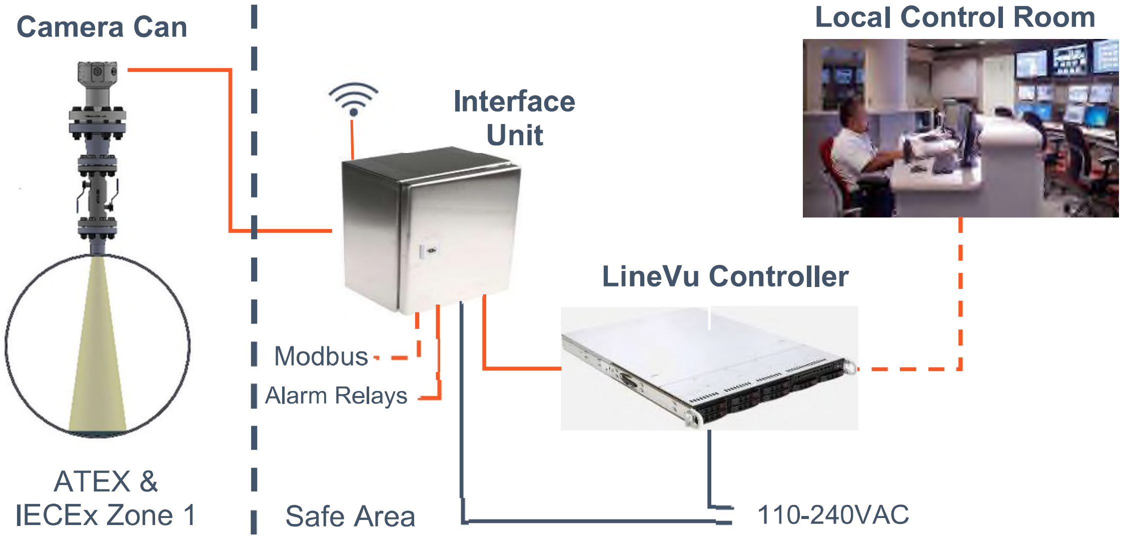

Figure 1. LineVu - the fixed system

The Camera Can is certified for use in hazardous areas, and designed to mount on top of a gas pipeline. The camera and illumination system is configured to take video and images of the pipeline through the isolation valve. Image processing is used to trip an alarm when contamination is detected. An optional link is available to the control room to provide a live view of pipeline activity.

The standard flange is a Class 900 3" RTJ. The Camera Can (*Figure* 2.) has a secondary containment vessel to prevent loss of containment upon a window or seal failure. The secondary containment vessel is constantly monitored for pressure and temperature. The SIM card in the interface unit allows connection to the mobile phone network via a secure link to enable technical support, including:

- Remote system commissioning, setting camera & illumination for optimum results
- Continuous health checks
- Upload of software updates
- Fault diagnosis
- Remote technical resources able to view live data to aid operational decisions
- Data monitoring

Figure 2. Camera Can

The interface unit and LineVu controller are mounted in a safe area, with an ethernet connection between them. Cybersecurity has been considered in the system's design with security features to ensure both system and data integrity. During the project, systems were not connected to the site Digital Control System (DCS) or National Grid networks. All data was saved on-site with sufficient space in the LineVu Controller to save up to a year of data. The alarm thresholds were set at a high sensitivity level with notification e-mails set up for Process Vision staff.

The LineVu system was set to store a still shot once a minute automatically. It compiles these shots into a time-lapse video which can be downloaded every 24 hours. This provides extra functionality beyond the detection of contamination. Replaying these videos at 1500x speed highlights and reveals low-level contamination (under alarm threshold) for further investigation.

The mobile system (*Figure 3*) was installed at a second site:

Figure 3. LineVu - the mobile system

These systems are designed for temporary installations for investigations. The interface unit and LineVu Controller are installed in transit cases, and there is not usually a connection for alarms or digital communications, e.g. Modbus.

Due to the sensitive nature of the results from this project, sections 8 to 12 are only available on request to National Grid Gas Transmission via the Smarter Networks Portal.

Thank you

13. Access to the Data

For staffed sites with a fixed system installed, an ethernet connection (via copper or optical fibre) can provide a live, high definition video of pipeline activity to be viewed in the control room.
Threshold alarms and system alarms can be configured for notification via:

- Relay activation
- E-mail notification – with still shots
- Text notification – with still shots
- Push notification – with still shots
- Modbus – not currently activated

As the system has access to the mobile phone network, cybersecurity has been considered in its design. There are several levels of security. The systems can operate independently of the operational or data networks operated by National Grid; all connections are via a secure link; all data uses encryption. Initial discussions have started with National Grid's IT department, and further measures can be taken to ensure system security is maintained at the highest level.

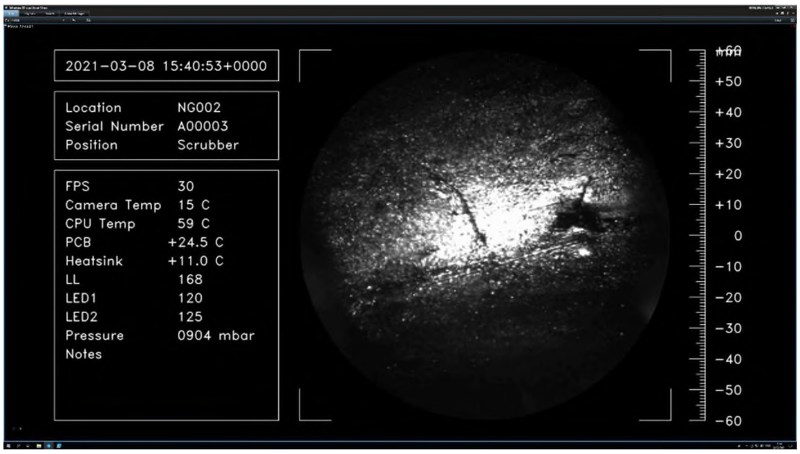

Figure 14. Web Interface

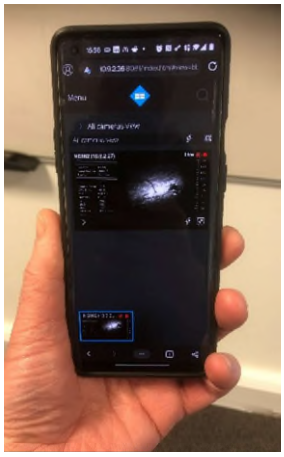

Figure 13. Mobile phone App

In addition to alarm notification, each system provides a web interface (*Figure 14.*) that can be accessed with the correct credentials and user authentication. Users can:

- View live video
- View historical video
- Export sections of footage
- Export snapshots for reports and shift logs

A mobile phone app (*Figure 13.*) is also available, again via a VPN for authenticated users.

14. Impact on Operations
a. Safety and Asset Integrity

Without monitoring systems, the NTS continues to be at risk.

Once in the NTS, liquid pools at low points in the network, causing internal corrosion that can lead to rupture, as at Carlsbad, New Mexico[2] (*Figure 16.*). The pipe was a 30-inch diameter, grade X52 pipe with a nominal wall thickness of 0.335 inches, and was cathodically protected.

Figure 15. Pipeline rupture at Carlsbad New Mexico

Figure 16. The crater left after the rupture

The pipeline was operating at approximately 675 psig (46 Bar(g)) at the time of the accident. The maximum allowable operating pressure in that section had been established at 837 psig (57 Barg). The force of the rupture and subsequent explosion created a 51-foot diameter crater (*Figure 15.*), with approximately 49 feet of the underground portion of the pipe ejected in three pieces from the crater. A large fire ensued, killing 12 people.

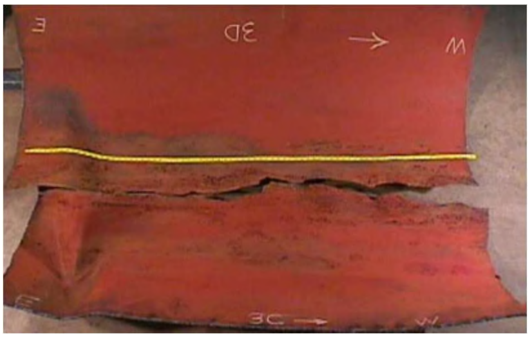

Figure 17. Pipe section from the rupture site.

Figure 18. Internal corrosion at the rupture site

The National Transportation Safety Board (NTSB) investigation concluded internal corrosion was the likely cause of the event, and the blocking of a "drip" upstream of the rupture site allowed liquids into the pipeline section. [redacted]

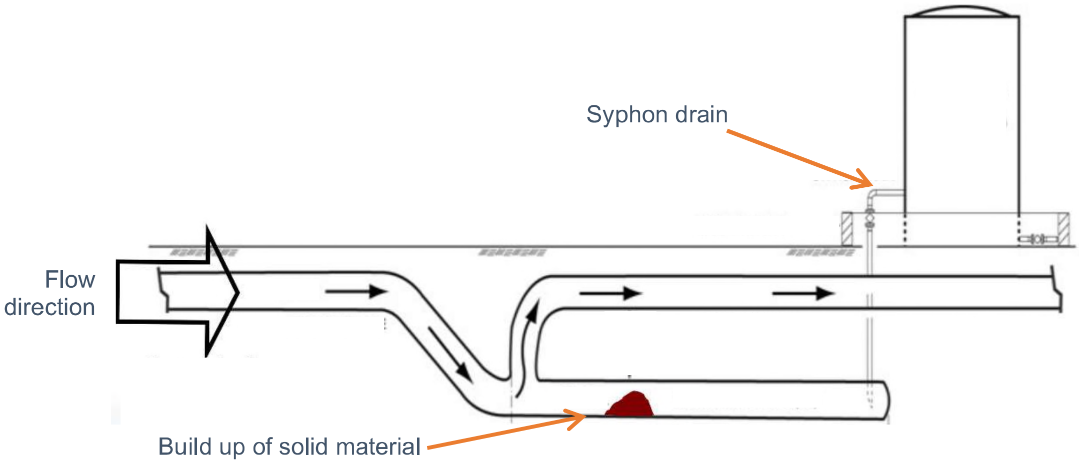

Figure 19. The drip upstream of the rupture site

The drip (*Figure 19.*) was a 40-foot-long stub line that branched off the bottom of the gas pipeline, and was designed to collect liquids and solids that may have built up in the pipeline. The drip was found to contain a blackish oily powdery/grainy material. At the area of its heaviest concentration, this material filled approximately 70% of the drip's cross-sectional area. The investigation concluded the event was:

> *"As a likely result of the partial clogging of the drip upstream of the rupture location, some liquids bypassed the drip, continued through the pipeline, and accumulated and caused corrosion at the eventual rupture site where pipe bending had created a low point in the pipeline."* [2]

> *"Had El Paso Natural Gas Company [the network] effectively monitored the quality of gas entering the pipeline and the operating conditions in pipeline 1103 and periodically sampled and analysed the liquids and solids that were removed from the line, it would likely have determined that the potential existed for significant corrosion to occur within the pipeline".* [2]

There have also been instances where liquids have accumulated at a low point to a sufficient quantity to cause a slugged flow. Slugged flows travel at high speed and, depending on the gas pipeline's topology, can contain high volumes of liquid. There have been many instances of damage to and failures of compressors due to liquids (*Figure 20.*) Gas turbines at power stations can also suffer damage from liquids. Hydrocarbon liquids landing on turbine blades can cause hotspots that will melt the blade. Solid material entrained in the liquid contamination can build up on the blade. In both cases, the turbine goes out of balance, causing severe damage.

Figure 20. Compressor failure

b. Reducing Contamination

Both licensees and the network are largely unaware of many contamination events and, if contamination is discovered, are unaware if it was due to a specific event or if the gas supply normally contains a level of liquids. This is due to existing gas quality measurement systems not monitoring for the liquids commonly found when material from pipeline pigging is analysed. These are mainly liquids used in gas processing and heavy hydrocarbons.
All gas quality analysis is performed at custody transfer points by sampling the gas in the pipeline from the middle third of the pipeline's diameter. *Figure 21*. shows the GPA guideline[5]. Sampling from the middle of the line (and further coalescing filters) protects the gas analysers from liquids travelling along the pipeline walls. When high levels of mist flow are present, it has been known for the filter systems on Gas Chromatographs (GCs) to be overrun, and liquids to block and damage the capillary tubes.

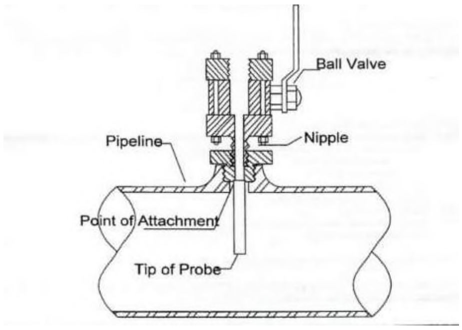

Figure 21. GPA guidelines for gas sampling.

The network can improve suppliers' accountability by implementing a LineVu threshold alarm, with operator actions similar to existing GS(M)R parameters, e.g. water and hydrocarbon dewpoint, and H_2S threshold levels.
Access to live data enables rapid evidence-based decisions to be made, and the recorded event will support and defend operational decisions made to maintain GS(M)R.
It is anticipated that with effective monitoring and adherence to GS(M)R (and tariff agreements), the effect of contamination will be reduced, lowering the frequency and severity of contamination events from licensees.
Faulty compressors that start passing lubrication oil into the gas flow can be serviced before the oil level alarm, alerting operators to the problem.
With live data, it is anticipated that network operators and licensees can take immediate and appropriate action.

- For the licensees, this action will reduce the loss of processing liquids and Natural Gas Liquids (NGLs).
- For the NTS, it:
  - provides the monitoring necessary to comply with GS(M)R.
  - will act as an early warning to gas analyser systems when mist flow is detected
  - will provide evidence to improve accountability of contamination events

c. Fiscal Flow Measurements

Wet Gas Flow

It is known that, if wet gas is present, orifice plate and ultrasonic flow meters used for fiscal measurements will over-read by around 5% [6]. Reporting wet gas flows by image processing is more sensitive than ultrasonic or other known methods.
With the gas flow at 9.5 MMnm3/day in Shell 3, the over-read equates to 0.48 MMnm3/day. Using gas prices for the time of the event equates to an over-read of around £34,790/day, a total over-charge of around £626K for the eighteen days of wet gas flow during the project.

Based on the project data, a conservative estimate of 7% of the time (25.5 days per year) of wet gas flow would cause an over-read of around £889K per year. The footage from Bacton shows that when gas was flowing, wet gas was present on the Shell 3 line for 47% of the time.

Solids

[redacted] Over time the rapid gas flow moving above the solid matter draws off the lighter end liquids, leaving a dry mass on the pipe wall.

The majority of the contamination found in networks is from gas processing, and therefore this contamination will pass through fiscal flow meter stations at the custody transfer points.

The solid material left on the pipe wall causes a small but permanent reduction in the pipeline diameter after an event. If this occurs at the point of flow metering, it results in a permanent over-read on flow measurements through which the contamination has passed.

[redacted] if this level of contamination was present at the flow meter station, it would cause an over-read of 0.335%. At current gas prices, this represents $1.2M per year [7].

Installation of LineVu systems could, therefore, have a positive impact on financial issues, and assist with fulfilling the due diligence requirements of the Sarbanes Oxley bill [8].

d. Mixed Phase Flows

Much work has been performed on mixed-phase flow loops to understand the process and define the different flow types observed[11]. Froude number is a helpful parameter when investigating mixed-phase flows. A Froude number for both gas phase and liquid phase elements can be plotted to generate a mixed-phase flow map such as the flow maps digitised from Shell DEP 31.22.05.111 [1]. in *Figure 22*.

The Froude numbers for gas and liquid may be calculated:

Gas Froude number: $FrG = vG\sqrt{\rho G}/\{(\rho L - \rho G)gD\}$

Liquid Froude number: $FrL = vL\sqrt{\rho L}/\{(\rho L - \rho G)gD\}$

Where:

vG	= velocity of gas	vL	= velocity of liquid
ρG	= density of gas	ρL	= density of liquid
g	= acceleration due to gravity	D	= internal diameter of pipe

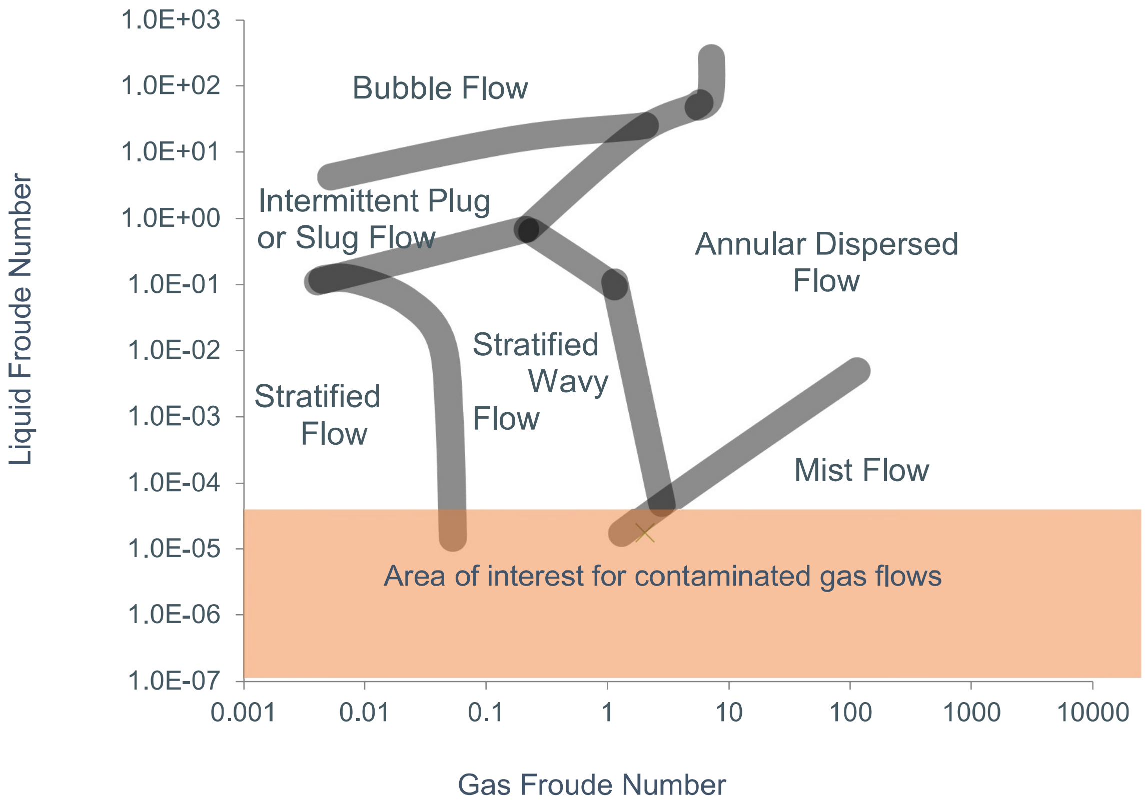

Figure 22. Mixed phase flow map

To some extent, the Froude number can be considered as the energy the fluid contains, a combination of its velocity and density. When liquids are considered a contamination of a gas flow, the Liquid Froude number (*FrL*) is low, usually below the 10^{-05} *FrL*. These types of phase maps infer that as the Gas Froude Number (*FrG*) increases, there is a transition from stratified flow (a stream at the bottom of the pipeline) through stratified wavy flow to mist flow.

Many of these maps have been generated from 2” or 3” diameter test loop data running pure liquids. This project has shown that the flow map above may not necessarily be the case in the real world. [redacted] As knowledge grows of the differences between real-World and CFD flow simulations, it will influence modelling capabilities and improve separator design.

15. Lessons Learned for Future Projects

The basic set-up of the system has remained the same throughout the project. The Interface Unit has been standardised with rail mounted components, and the LineVu Controller has also been standardised.

a. General

- [redacted] Thus, particulate and aerosol analysis performed by sampling using a probe could not provide the full picture of the contamination event.

- During the project, the videos have had great interest from National Grid operators and engineers. They provide new information about the gas condition that can not be gained from other instruments and analysers.
- The ability to alter the region of interest (ROI), illumination and focus remotely has proved valuable, as systems and conditions changed with different contamination flows and set-ups.
- Continuous health checks on temperature and the internal pressure revealed a small leak into the secondary containment vessel that was resolved before damaging the Camera Can.
- The live link aided fault diagnostics and resolution. Communication errors within the system sent alarms to the technical team, who could re-boot parts of the system immediately. On one occasion, a complete loss of power to the system was reported to the site immediately.
- It was possible to implement software updates via the live link without involving site staff and minimal system availability loss.
- The live link enables remote technical staff to view live data to aid operational decisions
- Data monitoring enabled a better understanding of unexpected pipeline conditions, with time-lapse videos being communicated to National Grid. It is expected that contamination activity under the alarm threshold would be reported to National Grid weekly and used to establish and review alarm thresholds on various events.
- Hydrocarbon dewpoint measurement, or its calculation from Gas Chromatograph (GC) data, can only include the gas phase element of the pipeline contents: the contamination observed flowing at the bottom of the pipe would not be detected.
- Providing immediate feedback on separator performance under different flow, pressure and temperature conditions will lower the loss of processing liquids and NGLs for licensees, and improve compliance with GS(M)R and asset integrity for the network.
- E-mail or text notification of alarm states, web access and the mobile app. could notify service engineers directly of problems assisting with an integrated workforce.
- Flow events do not necessarily follow phase maps.
- An event can start with any liquid flow type.

b. Guidelines For Installations

- The Camera Can should be kept as close to the pipe as possible with the minimum number of valves between the Camera Can and the pipe.
- If a DBB valve is not fitted, a ¼" tapping and bleed valve in the flange adapter allows for safe venting before removing the Camera Can for service.
- It is essential to perform a good site survey before attempting an installation.
- Using a 2" tapping point with a full bore valve will provide a good FOV. However, data can be retrieved from smaller diameter tapping points than thought initially.
- Data from other projects have shown that the combination of high gas velocity and installation immediately downstream of multiple tight bends creates sufficient turbulence to disturb the image. While the installation at [redacted] is downstream of three bends, there is adequate distance for the turbulence not to obscure contaminant detection.
- It is suspected that when contamination flows are observed at an angle to the pipe direction, it is due to a helical gas flow within the pipeline. This observation could be an additional benefit when installing LineVu at custody transfer points, where straight laminar gas flows are required for accurate flow metering.

- Control room operators have suggested that a live feed of pipeline activity would help put other process data into context. A fibreoptic line from the LineVu Controller to the control room will allow live high definition video of pipeline activity. Multiple LineVu systems can be displayed on one screen.
- During the project, gas flow, pressure and temperature were added to sections of footage that gave a better perspective of the events observed by linking them with changes in flow rate or other process parameters. The data could be added live if the system could read process data via Modbus or other digital data systems, providing cybersecurity issues are satisfied.

c. Updates Performed During the Project

- Update to O-ring configuration to improve small long-term leak rate into the secondary containment chamber.
- Re-configured data transfer from the Camera Can to Interface Unit to pure ethernet rather than a USB extender.

d. Actions after the project

- The output of the current LineVu is a big step forward in the detection of pipeline contamination events. It is anticipated that, with user discovery meetings, using GS(M)R as a guide, an acceptable alarm threshold and operator actions will be agreed upon.
- A second system installed on the separator's outlet at [redacted] would confirm its performance under different liquid loading observed on the inlet.
- Improvements to the FOV could be made by replacing the stop valve at [redacted] with a full bore valve at the next shutdown period.
- As the data from this and other projects are of sufficient quality and quantity, it could be possible to investigate reporting events in terms of severity via multiple alarm levels.
- Discussions should be held with National Grid flow metering engineers to fully understand the impact this data could have on fiscal measurements.
- Discussions should be held with National Grid IT engineers to discover the cybersecurity measures necessary for full compliance with National Grid requirements.
- Process Vision will continue to develop the LineVu product based on user feedback. With a safe window into the pipeline, a number of photonic technologies may be possible.

16. Outcome of the Project

Systems were installed at both staffed and unstaffed locations, and were able to communicate threshold and system alarms. With over 18-months in-service operation, the videos produced were of sufficient quality to provide compelling validation of the detection systems. They were able to bring a new understanding of the mechanisms in play when contamination occurs that may impact the measurement of other parameters.
The nature of contamination events in large diameter pipelines is beginning to be better understood. [redacted]

It has been found that some flow types do not obey conventional knowledge.
The optical limit of detection of LineVu is extremely good: 4 pixels. However, in practical terms, the sensitivity for the threshold alarm has to be reduced.

Detecting contamination at the gas entry point of the network could assist with the following issues:

a. **Safety and Asset Integrity.** Once contamination enters a gas network, there have been examples of it pooling at low points and causing internal corrosion to the point of rupture. There is also the risk that it accumulates to a point sufficient for slugged flow to occur. There have been events where liquids have caused significant damage to compressors and gas turbines - currently estimated at £1M per year in the UK [10].

b. **Compliance with Regulations and Tariffs.** With the evidence that LineVu provides, the NTS can improve its licensees' accountability by implementing threshold alarms at custody transfer points and its own compliance with GS(M)R by monitoring compressor stations. The recorded event will support and defend operational decisions made to maintain GS(M)R.

c. **Reduced Contamination.** It is anticipated that monitoring will lower the frequency and severity of contamination events from licensees, and lower the impact of faulty compressors that allow lubrication oil to enter the gas flow. Access to live data enables rapid evidence-based decisions to be made. Network operators and licensees can take immediate and appropriate action. For licensees, this action will reduce the loss of processing liquids and NGLs; for the network, it helps prevent contamination entry to the network, potentially lowering the frequency of pigging operations to clean-up after an event.

d. **Fiscal Flow Measurements.** The project findings have implications on the uncertainty budgets for fiscal flow metering. Wet gas and solid matter present at a flow meter station will cause errors in the measurement. Unexpected wet gas can generate around a 5% over-read on orifice plate and ultrasonic flowmeters[6]. Using a prudent estimate of 7% per year of gas flow being wet gas flow, this would result in a reclaim of around £889K per year on the [redacted] gas entry point. [redacted]
As contamination is unlikely to be pure liquid, the solid material left on the pipe wall is conveyed down the pipeline, causing a permanent reduction in pipeline diameter after an event. When this occurs at the point of flow metering, it results in a permanent over-read on flow measurements. Installation of LineVu systems could, therefore, have a positive impact on financial issues. Using the process details and observations from the [redacted] contamination could cause an over-read of around £876K per year at current gas prices[7].

[redacted]

The project found that the value of providing engineers with a live view of pipeline activity puts other process data into better context. If a method can be found to integrate process data onto the video without compromising cybersecurity, this would be beneficial. In addition, the project data has confirmed that contamination events can occur without other gas quality alarms being activated.
It is expected that the results of this project will have a broad interest across the gas industry.
The improved monitoring described in this project will lead to better gas quality, improved safety, and reduced operational costs.

17. Conclusions

The project has raised the awareness of contamination in gas flows received into the NTS and the industry's blind reliance on separator efficiency. The LineVu technology

- highlights separators and compressors that require maintenance
- highlight gas supplies that do not conform with GS(M)R,
- can improve the understanding of liquids and solids entrained in the gas flow

[redacted]

Operators could react to these alarms in the same way they would if the gas was outside of specification for water vapour or H_2S.
GS(M)R is in place to ensure the safe operation of the network. [redacted]

It is expected that this technology will start the process of:

- Improving gas quality
- Demonstrating compliance with GS(M)R
- Decreasing operational and asset integrity risk
- Improving accountability and allow clean-up costs of contamination by licensees to be allocated,
- Acting as an early warning to prevent damage to GCs and other instrumentation and plant

This project has demonstrated that the system is ready to move from research to business as usual.

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