Graham Jack, Halliburton, UK, discusses a new approach to identifying significant pipeline features using pressure wave analysis.

**Identifying key features**

The Halliburton InnerVue™ non-intrusive pipeline diagnostic service is a systematic, comprehensive approach to locating gas pipeline features by pressure wave analysis. The method is based on analysing return reflections generated by a pressure wave.
transiting a pipeline and reflecting from significant features. The pressure wave is generated by rapidly closing a mainline valve and recording the pipeline pressure in high resolution on an ultra high-speed logger. By applying acoustic gradient modelling in conjunction with the effect of pipeline material, deposits, drop-out fluid, and the dominant gas medium, fundamental features within the pipeline can be identified, located, and quantified.

By only requiring operators to connect instrumentation to the system via a small-bore connection, the InnerVue service is designed to avoid some of the significant issues that affect traditional technologies, such as access to the pipeline – whether because of the requirement to physically insert a tool when it could lack access points into the pipeline, or to access it externally when buried or subsea.

Ultimately, with these technologies, the pipeline operator needs to balance the potential risk vs reward with these methods to determine which, if any, to choose.

**Operational process**

When an InnerVue non-intrusive pipeline diagnostic service is required by a pipeline operator, a single Halliburton technician – along with the ultra high-speed data logger contained in a small travel case – are mobilised to the worksite.

The ultra high-speed data logger recording at an equivalent 4000 data points/sec. is connected at either the inlet or the outlet end of the pipeline, which is placed in a stable flowing state with no significant pressure fluctuations. Once this is confirmed, the data logger is set to record pipeline pressure; the pulse is generated, and pressure variations are monitored and recorded to produce a signature.

The pulse is created by operating a quick-closing time valve at the same location the data logger is connected, therefore retarding flow and creating a fluid hammer or pressure wave within the pipeline. The valve closed to generate a pressure wave is kept closed during the survey. The wave traverses the pipeline to the endpoint, then reflects and travels back to the pressure transducer point, where the valve can be opened and normal production resumed.

Once the data collected at the worksite is uploaded to the proprietary cloud-based software, the data sets are normalised, compared for repeatability, and reviewed for anomalous readings. After abnormal data sets are discarded, the remaining are analysed individually. The data from the field is compared to the simulated model of the pipeline, designed using details provided by the operator on the fluid and system. The deposit profile and pipeline internal bore are then extrapolated using numerical iterative algorithms.

During analysis, the characteristics are adjusted to reflect the operating parameters of the pipeline as flow, pressure, and temperature all impact the density and compressibility of the gas. This has a direct effect on bulk modulus and the relative speed of sound of the gas at any given point in the system, which, in turn, makes the transit of any pulse within the pipeline unique – specific to the shape of the pulse generated and its transit through the system.

It is imperative that the acoustic velocity of the gas being transported in the pipeline is known as accurately as possible. It is therefore crucial that the pipeline parameters, such as pipeline internal diameter, pipeline wall thickness, Young’s modulus, gas composition, relative compositional molecular weight, adiabatic constant of the gas composition, and system temperature, are known.

The ideal gas theory and adiabatic propagation are then determined from the bulk modulus, and the unrestrained acoustic velocity in gas can be calculated. Once this unrestrained acoustic velocity is known, a modified Hooke’s law formula can be used to combine it with pipeline characteristics to define the restrained acoustic velocity. Geometrical profiling can then be performed using the Darcy-Weisbach equation to determine the frictional pressure drop, thereby obtaining a time log of the pressure change in the pipeline as measured. This can then be used to calculate the hydraulic diameter throughout the length of the surveyable system.
Supporting results
This theoretical model supporting the approach is endorsed by results observed when using it to identify features within pipeline systems. Results from field operations demonstrate that InnerVue non-intrusive pipeline diagnostics can be used to identify the location of valves, tees, wyes, and bore changes in gas pipelines – both onshore and offshore.

The theoretical model for acoustic velocity estimation for systems where the pipeline parameters and gas properties are understood is also proven to be correct within tolerance when compared to the acoustic velocity observed in the field, by recording the time of flight between two known points. The data from the field demonstrates that pipeline features can be accurately detected; this is verified by comparing analysed data against known pipeline features within a system.

As part of the validation of the methodology, a pipeline test loop was made up of 1800 m of 4 in. nominal ID pipe. Approximately midway, a 10 m section was replaced with 2 in. ID pipe, and the system was filled with pressurised air. Over a period of five days of testing, more than 200 surveys were performed across a multitude of scenarios. The objective of the testing programme was to validate the baseline/bench test results, which calibrated the science and software, and allowed progression to the next stage of development of creating a field-deployable system.

Review of the data showed that pulse generation, signature response of the deposition fixture, and end-of-pipe reflex were clearly visible at the locations predicted by the theoretical model. Extrapolation of the hydraulic diameter per data point against the transient passage timing provided an acutely accurate location and geometrical order of change in relation to the deposition fixture.

Field test
Following the successful trials with the pipeline test loop, the InnerVue non-intrusive pipeline diagnostic system was deployed in the field. The objective was to locate some lost magnets, which were slightly larger than a deck of playing cards, that had become detached from an inspection tool. At crossings under roads and canals, pipe wall thickness was increased for added strength.

This added thickness – which was situated on the inner side of the pipe – provided features of known location, length, and order of change in the diameter. The pipeline system was approximately 20 km long and 12 in. nominal diameter, and the medium was sales gas – a network supply specifically serving several industrial operators.

Measurements were performed in sections – isolating the system where appropriate, for most cases – surveying upstream from the measurement/pulse initiation point. Each section contained a diameter reduction of 7.8 mm, corresponding to a geometrical change of 3.9 mm in relative hydraulic diameter. Because of the configuration around the closing valve, there was significant random noise in the data, which eliminated the opportunity to make assessments for the location of the lost magnets from the inspection tool. Despite this, the data was extremely interesting because the line had various changes of wall thickness where crossing roads and canals. These ID changes could be seen in the data and their size and location extrapolated during analysis, with the results within distance and order of diameter change tolerance when compared against the known system details.

Conclusion
In conclusion, the methodology and application can be considered validated for addressing the challenges of profiling geometry and debris build-up throughout an entire pipeline system quickly, non-intrusively, without access-constraint issues, or risk of an intrusive intervention. It is evident that the approach is repeatable at a high level of accuracy and that a field-deployable solution is also identified and proven.

Looking toward the next stages of development, it is encouraging to have high confidence in the applicability and readiness of this application in large-diameter natural gas pipelines, where it is known that the dominant variable parameters of gas composition and temperature would be available and accurate.

Of particular consideration is that a body of pooled liquids in a gas pipeline system has a response effect on the induced pressure wave, providing the ability to extrapolate the location and volume of static liquids from the data. This information in turn significantly enhances liquid hold-up and corrosion monitoring or prevention programmes, in addition to supporting planning and execution for successful inline inspection operations.