Technology Transfer from the Natural Gas Industry to Other Compressible Fluids

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Introduction

The transport and energy measurement of natural gas is well understood. ISO standards and best practice specifications and procedures to facilitate transport and custody transfer are widely available and under constant improvement and review.

A natural gas transmission system is a combination of the assets (pipeline, valves etc) and measurement systems for flow control, line pack calculations and custody transfer billing. Energy measurement facilities are installed at all custody transfer stations such as beach reception terminals, LNG export-to-grid, interconnectors and city gate/transmission offtake points.

This paper and poster seek to outline how technology and methods developed in the natural gas transmission industry at custody transfer points can be transferred to the transport of other compressible fluids. Carbon dioxide (CO_2) is used as a specific example as CO_2 transport is becoming increasingly important for carbon capture and storage (CCS) and enhanced hydrocarbon recovery. Accurate measurement and billing for CCS is required to show compliance with national and international emissions-reduction regulations and to receive payment for the CO_2 sequestered.

The mature natural gas industry can apply technology transfer methods to CO_2 transport and measurement to identify the "known knowns" and the "known unknowns" [1]. This still leaves the "unknown unknowns" but these can be minimised, but not eliminated, by targeted experimental testing.

Custody Transfer

Custody transfer refers to transfer of ownership of a fluid from one operator to another. This includes transferring raw and refined products between tanks and tankers, tankers and ships, ships and pipelines and from one pipeline to another. Custody transfer in fluid measurement is defined as a metering point (location) where the fluid is being measured for sale. As part of the custody transfer, the quality of the fluid may be checked and measured to ensure that it complies with the custody transfer contract or with local regulations; quality checking often occurs at international boundaries and at entry points to transmission pipelines to protect the end-users and to ensure the integrity of the transmission assets. The fluid quality check and the properties are also required for accurate custody transfer measurement.

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[1] The US Defence Secretary Donald Rumsfeld stated at a news briefing in 2002:

"…..*there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns -- the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tends to be the difficult ones*".

There are four drivers for custody transfer measurement (see Figure 1); statutory regulations, commercial/legal agreements, taxation and protection of the transmission assets. All four are achieved by measurement of fluid quantity and quality according to:

- Industry standards (ISO, EN etc)
- Contracts between two operators for billing
- Government regulation for safety reasons
- Government regulation for taxation including emissions trading

The contracts between the operators will also specify uncertainties and errors of measurement to define the type of instrumentation that should be used. Custody transfer measurements are often required to be traceable through the metrology chain to national and international standards.

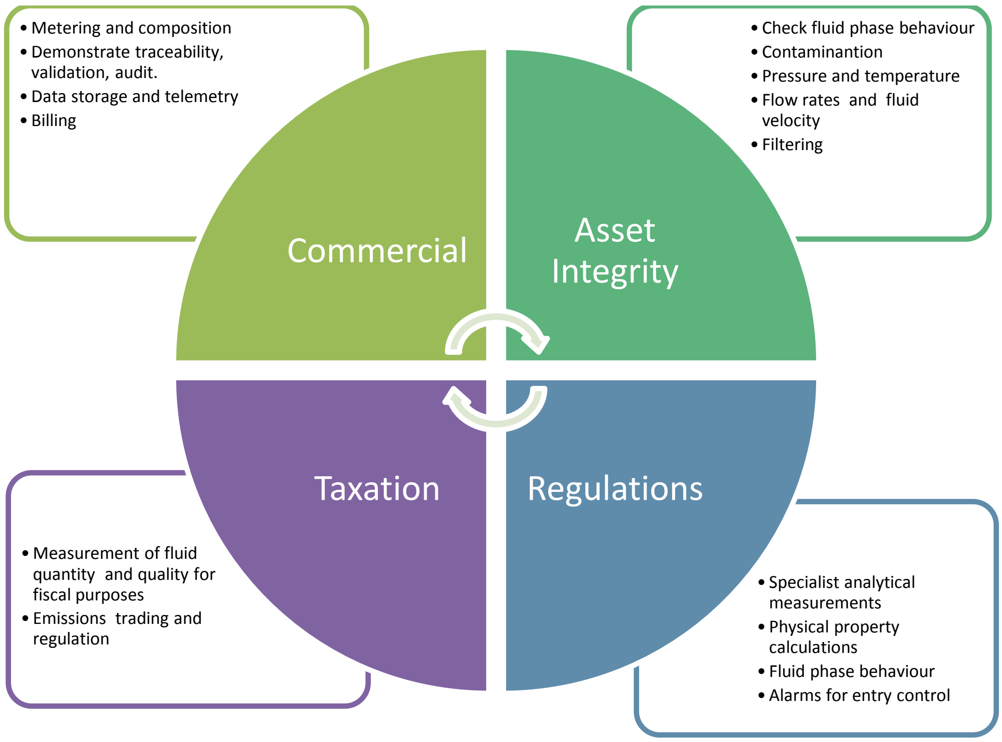

Figure 1 The drivers for the custody transfer and transport of fluids

Custody Transfer for Natural Gas

The custody of natural gas is transferred a number of times throughout the journey from production to consumption. A producer of natural gas sells the gas to a Shipper who, in turn, has a contract to deliver the gas to a consumer. In order to deliver the gas to the consumer, the Shipper entrusts the gas to a Gas Transporter who receives the gas (usually at a gas terminal) and delivers the gas at an offtake from the transmission system. The gas may then be delivered directly to a consumer (for example a power station) or it may be handed over to another Gas Transporter (a gas distribution company) who successively reduces the pressure and delivers the gas to commercial and domestic premises. Gas Transporters usually do not own the gas they transport – they own the pipeline and all the associated assets and they earn income from operating the pipeline to transport the gas. An example of where custody transfer measurements are made on a natural gas network is shown in Figure 2 – the points in the journey at which the gas passes from one party to another are outlined in red. In recent times, non-conventional gases, such as biomethane, may enter the network at lower pressure tiers – these “grid-injection” points have become custody transfer entry points to a network.

The transport and energy measurement of natural gas is well developed for flow control, custody transfer, line pack and billing purposes. Energy measurement facilities are installed at all custody transfer stations such as beach reception terminals, LNG export-to-grid, interconnectors and city gate/transmission offtake points. These energy measurement facilities comprise:

- Volume or mass flow measurement (meters)
- Gas quality instrumentation (analysers)
- Pressure and temperature measurement
- Flow computers implementing equations of state and international standards
- Supervisory systems, telemetry, back-up power supplies and other equipment.

At entry points to national transmission networks, further extensive gas quality measurements are made to ensure compliance with statutory and contractual requirements:

- Fluid phase behaviour is checked to ensure transportation in the gas phase with no liquid dropout; this is achieved by determining the natural gas hydrocarbon and water dew points from detailed compositional analysis and an appropriate equation of state
- Gas properties are checked to ensure safe combustion and to protect the integrity of the pipelines and other assets during transportation. Examples of gas properties are Wobbe Index, relative density, calorific value, sulphur content, line density and so on.

Equations of state and international standards are implemented on flow computers and these are agreed in the metering contract. Natural gas is usually transported from a high-pressure tier to a lower-pressure tier at the point of use.

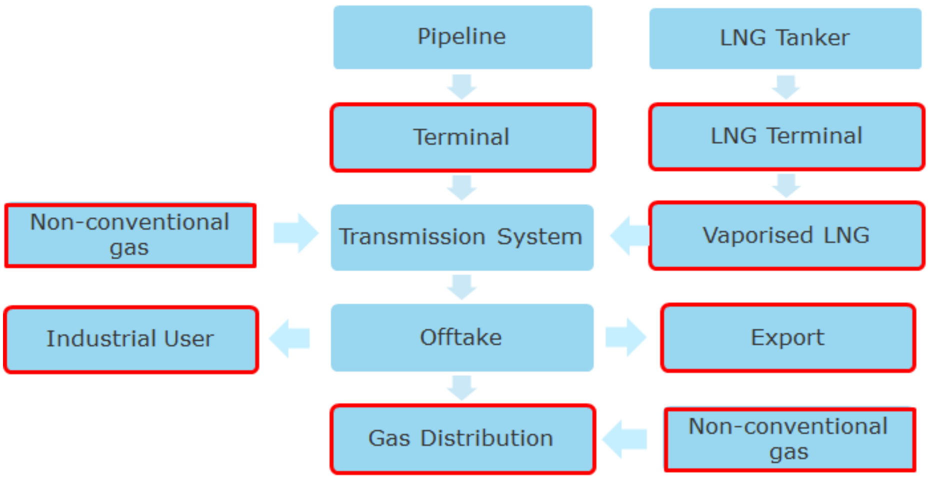

Figure 2 Custody transfer measurements are usually made at the transfer points outlined in red.

Custody Transfer for Carbon Dioxide

Custody transfer during the transport of CO_2 from production to its point of use or storage also occurs at a number of different locations

For CCS applications, the CO_2 is either captured from raw natural gas or produced by the combustion of a fossil fuel at, for example, a power station and the flue gas is processed to capture a CO_2-rich fluid. After leaving the clean-up plant, the custody of the CO_2 is likely to be passed to a pipeline company who transport the CO_2-rich fluid to the reception terminal at the storage facility. At the storage facility the fluid may be compressed further to increase the pressure and pumped to an underground storage location. The quantity and purity of the CO_2 sent to storage may need to be reported to a statutory body to ensure compliance with regulations such as the European Union Emissions Trading Scheme

(EU-ETS); the measurements are also used for billing and they therefore become the cash register for the transport system.

Technology Transfer from Natural Gas to CO_2

CO_2-rich fluids behave very differently to natural gas in terms of phase behaviour and thermophysical properties. Natural gas transmission systems are largely designed to operate at the local ground or ambient temperatures (for example between -20 and 50 °C) and at pressures between about 40 and 85 bar. The density of natural gas at these conditions varies from about 25 to 100 kg/m^3. The natural gas is processed by the producers to ensure that there will be no liquid dropout during transmission and that the combustion and other physical properties are suitable and safe at the point of use.

The phase diagrams of natural gas and carbon dioxide have been plotted together in Figure 3. The operating domain for a typical natural gas transmission system is shown by the red box – in this region, natural gas is well away from its two-phase region and the system is operating in the gas or supercritical fluid region of the phase diagram. Unfortunately, for CO_2 this operating domain would be unsuitable because the vapour pressure curve, which is the transition between the gas and liquid phases, passes right through the middle of the red box. Additionally, whereas the maximum density of transmission natural gas is about 100 kg/m^3, the corresponding densities of CO_2 range from 100 to 1000 kg/m^3 and the fluid flow is more like a liquid than a gas. When impurities are added to CO_2 the two-phase region goes from a line to a loop as shown in Figure 4; this makes the transport of CO_2 at the conditions familiar to the natural gas industry even more challenging.

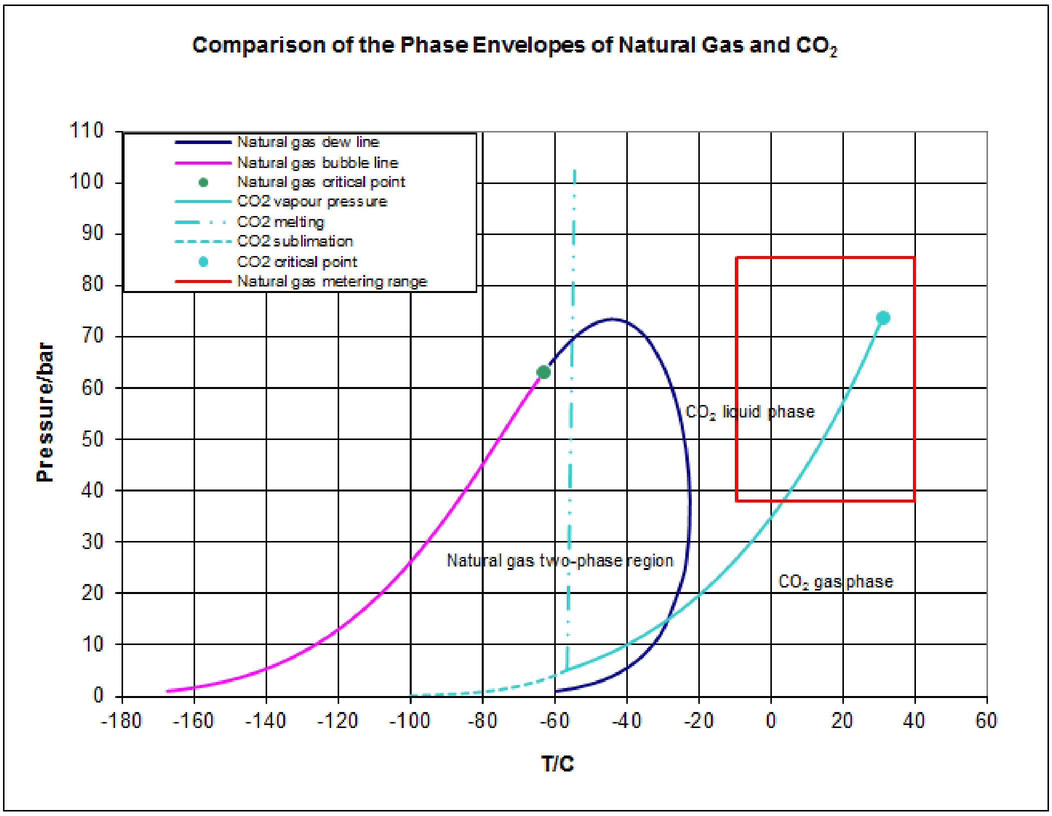

Figure 3 Comparison between the phase envelopes of natural gas and CO_2

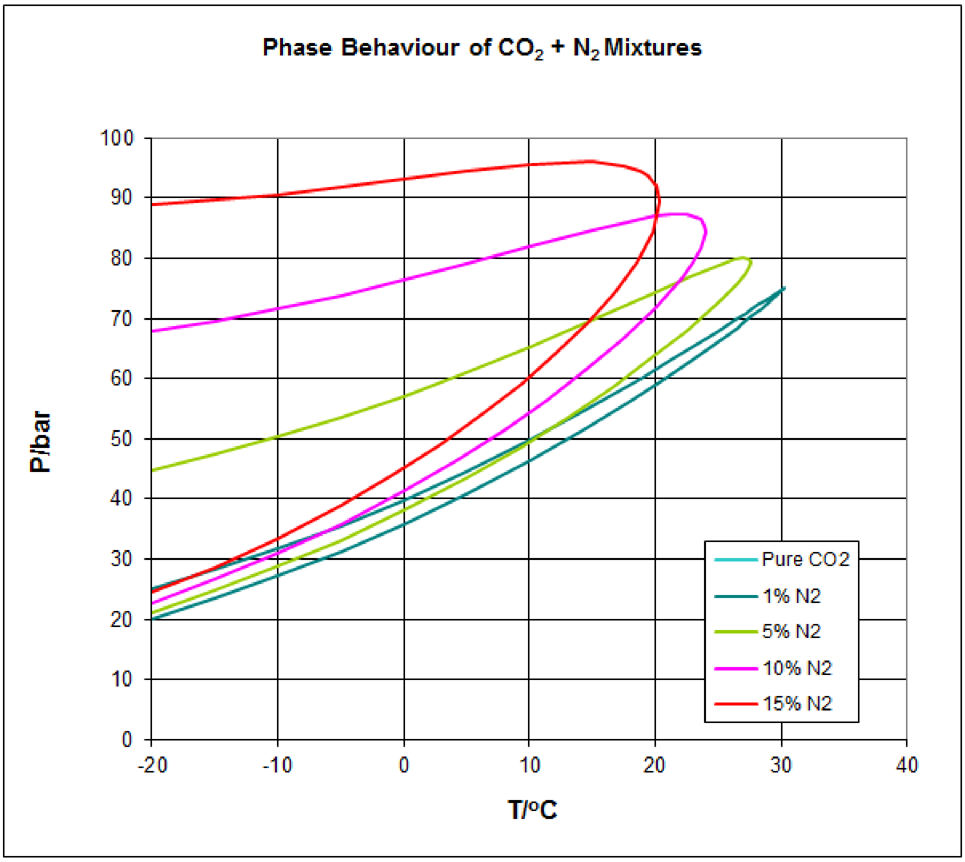

Figure 4 Phase behaviour of CO_2 and typical impurities such as nitrogen

A comparison between the measurements required for the custody transfer of natural gas and those likely for CO_2 is given in Table 1.

Conclusion

Technology transfer can be used to identify the "known knowns" and the "known unknowns" by applying well-established industry knowledge from the transport of natural gas to the transport of CO_2. Only by building a full-scale prototype custody transfer system for CO_2 will it be possible to confirm that the "unknown unknowns" have been minimised as far as possible.

Property	Commercial	Asset Integrity	Regulation	Tax	Requirement/Issue	Natural Gas	CO_2
Mass or volume flow	●	●	●	●	Ultrasonic meter for volume flow	Well established – calibration facilities available	Not available due to severe signal attenuation. May be possible for small pipe sizes. No calibration facilities.
					Turbine meter for volume flow	Well established – calibration facilities available	No calibration facilities.
					Orifice plate for mass flow	Well established – calibration facilities available	Suitable for all pipe sizes. Calibration as for natural gas. Elastomer seals not suitable due to solubility of CO_2
					Flow computers	Well established	May be only one model suitable
					Equations of state	AGA8 or ISO 12213 methods for density calculation	GERG-2008 or similar required – only implemented on one flow computer
					Pressure	40 to 100 bar typical. Well established.	<30 bar ("gas" phase) or >150 bar ("dense" phase). Pressure rating lower or higher than natural gas. Care required with selection of surfaces in contact with CO_2.
					Temperature	-20 to 50 °C (ground temperatures)	-20 to 50 °C (ground temperatures)
					Fluid quality	Sampling, pressure let-down and gas chromatography analysis up to C6+ with nitrogen and CO_2	Special sampling and heating due to pressure drop from 150 bar or higher to atmospheric. Gas analysis may need testing for long-term operation.
Phase	●	●	●		Detailed	Composition analysis up to C9 or	Composition analysis for 95 mol% CO_2

Property	Commercial	Asset Integrity	Regulation	Tax	Requirement/Issue	Natural Gas	CO_2
behaviour					analysis to determine dew, bubble and critical points	C12. Hydrocarbon dew points calculated using equation of state or measured directly using chilled mirrors or similar. Critical point usually not an issue. Measurement techniques well established	with N_2, O_2, methane, SOx, NOx.etc Concern with bubble points (dense phase), dew points (gas phase) and critical region. Specialist process gas chromatographs to determine H_2S, SO_2, O_2+Ar, N_2, CH_4 and CO are available but need testing.
					Analysis of water content	Electrochemical cells - water content controlled either on water concentration or dew temperature. Typical concentration 55 ppm. Water drops out as a separate non-reacting phase	CO_2 is soluble in water and carbonic acid is highly corrosive. Pipeline limits likely to be of the order of 200 ppm or less but CO_2 stream likely to be drier due to upstream processing. Analysis using hygrometer may be suitable but will need testing at high line pressures.
Fluid velocity	●	●			Controlled due to pipe erosion and noise	Up to 30-40 m/s typical. May be reduced to 20 m/s through measurement systems	Dense phase likely to move at <3 m/s. Gas phase 10 m/s typically. Fluid velocity not expected to be an issue.
Combustion	●		●	●	End user safety	Calculated from gas composition	Not flammable
Hazardous areas	●		●		Zoning	Intrinsic safety requires electrical isolation between field equipment and safe area.	No hazardous area rating – not flammable. No isolation from field equipment required. CO_2 is an asphyxiant so care needed with pipeline leaks and escapes. Potential solid formation with temperature drop caused by uncontrolled release.

Property	Commercial	Asset Integrity	Regulation	Tax	Requirement/Issue	Natural Gas	CO_2
Hydrogen sulphide	●	●	●		Toxicity and corrosion	Corrosive in presence of water. Can cause stress corrosion cracking and hydrogen induced cracking. Controlled to < 3.3 ppmV in the UK and measured using gas chromatography.	Gas chromatography probably suitable.
Oxygen		●	●		Accelerates corrosion	Typically controlled to 0.001 to 0.1% mol/mol depending on network and whether gas is going to storage. Measured using electrochemical detectors.	An electrochemical sensor provides the best on-line measurement of oxygen. Other techniques not suitable - paramagnetic analysers respond to CO_2 and zirconium dioxide sensors convert the O_2 to CO_2 in the presence of CO and/or CH_4.
Hydrogen		●	●		Safety	0.1 mol% in UK but higher in some networks. Impact on pipeline and combustion. Measured with electrochemical detectors.	Up to 4 mol% possible but the impact on the phase behaviour and the pipeline materials to be assessed.
SOx		●			Corrosion issues	Not an issue with natural gas	Highly reactive in presence of water and oxygen to form corrosive acidic phase. SO_2 could be analysed by a process chromatograph
Particulates	●	●	●		Erosion and blockages	Filters	Filters – additional risk of blockage during storage

Table 1 Comparison between the custody transfer of natural gas and CO_2