A Multi-source Flow Model for CCS Pipeline Transportation Networks

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Abstract

As part of the operation of the carbon capture and storage process, there are clear practical and economic incentives in employing an integrated pipeline network system involving the capture of CO₂ from multiple emission sources such as power plants or steel works followed by injection into a single storage site. This paper presents the development and testing of multi-source flow model for predicting the entire flow conditions such as pressure, temperature, fluid phase and CO₂ composition throughout the pipeline network and the delivery to the storage site. The model also accounts for pipeline elevation and periodic variations in feed source flow rate, for example as a result of the ramping up or ramping down of power production from coal fired power stations connected to the pipeline network. The ability to produce the above information is of vital importance given the large impact of the stream impurities on the CO₂ phase behaviour and their physiochemical interactions with the pipeline material of construction, compressor power requirements and the storage reservoir performance.

KEYWORDS:

CCS pipeline transportation; thermo-hydraulic model; Multi-source network

1. Introduction

The internationally agreed objective of limiting the increase in global average temperatures to less than 2 °C above pre-industrial levels requires a 50–80% reduction in CO₂ emissions by 2050 (Edenhofer et al., 2011). Alongside renewable energy sources CO₂ Capture and Storage (CCS) is widely considered as a key technology for meeting this target, potentially reducing the cost of inaction by some \$2 trillion over the next 40 years (IEA, 2012).

It is estimated (Element Energy, 2010, IEA, 2010) that transporting the predicted 2.3–9.2 Gt of captured CO₂ to its point of storage will require the use of a global network of between 95,000 and 550,000 km of pipeline by 2050.

It is generally accepted that the use of integrated pipeline transportation networks likely represents the most practical and economical means of transporting the captured CO₂ (Knoope et al., 2014, Lazic et al., 2013, Wetenhall et al., 2014) from various emission sources such as power plants and cement manufacturing industries for sequestration as compared to individual pipelines, through lower capital costs and reducing permitting issues (Knoope et al., 2014).

The application of different types of CO₂ capture technologies (pre-, post- and oxy-combustion) to different CO₂ sources (coal-, gas-power as well as industry) has the potential to lead to varying qualities of CO₂ stream being injected into the transport network. This represents a practical dilemma given the established impact of the various impurities on many aspects of the CCS performance.

For example, impurities have a marked impact on the CO₂ phase behaviour (Oosterkamp and Ramsen, 2008). In the context of the pipeline transportation, this is important as it is necessary to avoid phase change due to the significant operability problems associated with two-phase flow.

The physiochemical interactions of the impurities with the pipeline material of construction impact pipeline's propensity to ductile (Mahgerefteh et al., 2012) and brittle fracture failures (Bilio et al., 2009) as well as resistance to corrosion (Ruhl and Kranzmann, 2013). Impurities may also impact the storage performance through reduced storage capacity and injectivity

(IEAGHG, 2011) through chemical interactions with the porous structure or, in the case of non-condensable impurities (O_2 , N_2 , etc.), raise the Minimum Miscible Pressure (MMP) in the reservoir. The latter requires a higher pressure which introduces the risk of damaging the integrity of the caprock.

All this means imposing restrictions on the levels and types of contaminant that may be tolerated both within the pipeline network and injection into the storage site, including the pipeline delivery pressure, temperature and flow rate.

An ability to accurately model the flow within a pipeline network, in particular the pressure drop, fluid phase and precise stream composition including the mixing of the various source streams and the delivery conditions is therefore essential.

Current work, however, has either assumed that the stream is pure CO_2 (Knoope et al., 2013, Knoope et al., 2014) or that the stream contains impurities but that the composition fed from each source is the same (Wetenhall et al., 2014). Both of these assumptions, as described above, are likely to underestimate the amount of compression that is required in the network as whole and hence are incapable of predicting the delivery conditions and composition accurately.

Furthermore, the amount of CO_2 produced from each source will change over time depending on the economics of its production (Domenichini et al., 2013, Mac Dowell and Shah, 2013, Mac Dowell and Shah, 2014). Transition between these different source conditions will alter the flow behaviour, i.e. pressure drop in the system and result in a variation in the composition of the delivered CO_2 stream.

The objective of this study is to present a model which describes the steady state flow in a network of CO_2 transportation pipelines containing various sources of CO_2 and, importantly, which accounts for the presence of differing contaminants and their levels in the incoming streams and hence accurately predicts the final delivery composition and fluid conditions.

This paper is organised as follows. The steady state multicomponent flow model, along with the pertaining assumptions, and its extension to pipeline branches are presented. In the absence of experimental data for validation of the model, a hypothetical, but realistic, multi-

source CCS pipeline network in the UK is introduced as a case study. This is then followed by the application of the model to the system under investigation and a discussion of the results obtained along with conclusions drawn.

2. STEADY-STATE FLOW MODEL

2.1. Pipeline network model

Transportation of compressible fluid such as CO₂ in a long pipeline may result in significant changes to the pressure and temperature of the fluid along the pipe length due to the effects of frictional pressure drop, expansion work by the fluid and heat exchange with the pipeline surroundings. To accurately model these effects, the following mathematical model of non-adiabatic steady-state flow, based on the mass, momentum and energy conservation equations is applied:

$$\frac{d(\rho u)}{dx} = 0 \quad (1)$$

$$\frac{d\rho u^2}{dx} = -\frac{dp}{dx} - f\frac{\rho u^2}{2D} - \rho g \sin \theta \quad (2)$$

$$\frac{d\rho u \left(h + \frac{1}{2}u^2 \right)}{dx} = \frac{4q_w}{D} - f\frac{\rho u^3}{2D} \quad (3)$$

where x , D , ρ and h are the local coordinate along the pipeline, the pipeline diameter, the density and enthalpy of the fluid respectively. u , P , f , q_w and θ on the other hand respectively represent the velocity of the flow, the fluid pressure, the Darcy friction factor, the heat flux at the pipe wall and the angle of inclination of the pipeline with the horizontal axis.

In addition to equations (1–3) conservation equations are applied for each component, i , of an n component mixture:

$$\frac{dz_i}{dx} = 0, \quad i = 1, \dots, n. \quad (4)$$

It is assumed that the fluid is a homogeneous mixture of all components, i.e. it is well-mixed. For turbulent flow in a straight pipe, the Darcy friction factor can be calculated as a function of Reynolds number and relative roughness of the pipe wall using the Colebrook–White equation (Coulson and Richardson, 1999):

$$f = \frac{0.25}{\left[\lg \left(\frac{\varepsilon}{3.7 \cdot D} + \frac{5.74}{\text{Re}^{0.9}} \right) \right]^2} \quad (5)$$

where, ε is the wall roughness and $\text{Re} = \rho u D / \mu$ is the flow Reynolds number and μ is the dynamic viscosity of the fluid.

The heat flux, q_w at the pipe wall is defined via the heat transfer equation:

$$q_w = \alpha \cdot (T_{amb} - T_f) \quad (6)$$

where the T_{amb} and T_f are respectively the temperatures of the medium surrounding the pipe and the fluid inside the pipe. α is the overall heat transfer coefficient.

Figure 1: Cross-section of a buried and insulated pipeline

Figure 1 shows the cross-section of a buried pipeline. Here D_o , δ_{ins} and d_{soil} are respectively the external diameter, thickness of insulation and radius depth of the pipeline from the ground surface. In case of a buried and insulated pipeline as represented in Figure 1, the overall heat transfer coefficient is defined as:

$$\alpha = \left[\frac{1}{\alpha_f} + \frac{D}{2\lambda_w} \ln\left(\frac{D_o}{D}\right) + \frac{D}{2\lambda_{ins}} \ln\left(\frac{D_o + \delta_{ins}}{D}\right) + \frac{D}{2\lambda_{soil}} \ln\left(\frac{d_{soil}}{D}\right) + \frac{1}{\alpha_{amb}} \frac{D}{2d_{soil}} \right]^{-1} \quad (7)$$

where λ_w , λ_{ins} and λ_{soil} are the thermal conductivities of the pipewall, insulation and soil respectively. α_f and α_o on the other hand are respectively the heat transfer coefficients on both the internal and external sides of the pipe wall. Both values are calculated using standard correlations for forced and natural convection heat transfer (Mahgerefteh et al., 2007).

2.2. Pipeline network model

The application of the flow model described above to networks requires a methodology for predicting the flow conditions at junctions. At such junctions differing streams from several pipe segments may merge together into one pipe for further transportation. Figure 2 shows a schematic representation of the simplest case of these, the Y-junction.

Figure 2: Y-junction connecting three pipe segments of a pipeline network. Flows from Pipe 1 and Pipe 2 are merged into Pipe 3.

For the case of a Y-junction, pressure, energy and momentum losses are assumed negligible, the first of these is justified as these losses are likely to be at least two orders of magnitude smaller than the pressure drop along the pipe sections. The mass, momentum and energy balances can be respectively written as:

$$\rho_1 u_1 A_1 + \rho_2 u_2 A_2 = \rho_3 u_3 A_3 \quad (8)$$

$$p_1 = p_2 = p_3 \quad (9)$$

$$\left(\rho_1 u_1 h_1 + \frac{1}{2} \rho_1 u_1^2 \right) A_1 + \left(\rho_2 u_2 h_2 + \frac{1}{2} \rho_2 u_2^2 \right) A_2 = \left(\rho_3 u_3 h_3 + \frac{1}{2} \rho_3 u_3^2 \right) A_3 \quad (10)$$

$$\rho_1 u_1 z_{1,i} + \rho_2 u_2 z_{2,i} = \rho_3 u_3 z_{3,i}, \quad i = 1, \dots, n. \quad (11)$$

The above equations can be generalised to describe conditions at a junction of k pipes:

$$\sum_{j=1}^{k-1} \rho_j u_j A_j = \rho_k u_k A_k \quad (12)$$

$$p_j = p_k, \quad j = 1, \dots, k-1. \quad (13)$$

$$\sum_{j=1}^{k-1} \left(\rho_j u_j h_j + \frac{1}{2} \rho_j u_j^2 \right) A_j = \left(\rho_k u_k h_k + \frac{1}{2} \rho_k u_k^2 \right) A_k \quad (14)$$

$$\sum_{j=1}^{k-1} \rho_j u_j A_j z_{j,i} = \rho_k u_k A_k z_{k,i}, \quad i = 1, \dots, n. \quad (15)$$

where the symbols have the same meaning as previously described.

2.3. Numerical Solution Method

The solution of the flow within the pipeline network given the inlet flowrates and temperatures at each source proceeds as follows:

1. First the feed pressures at the sources of the network are guessed.
2. The steady-state flow is calculated in each individual segment sequentially along the network, using the set of mass, momentum and energy conservation equations (1-4), which are solved with an implicit Euler method using a constant step length along each segment. Prior to this the balance equations at the segment inlet (equations 12, 13 and 15) are solved and for junctions the inlet pressure is assumed to be p_1 , i.e. the pressure at the end of one of the pipes entering the junction. In this manner the inlet flowrate, composition and temperature conditions are provided.
3. The pressures at the sources of the network are iterated until equation (13) is satisfied at each junction in addition to the pressure at the delivery point being that specified, for this purpose we use the differential-algebraic solver DASSL (Petzold, 1982).

The pertinent thermodynamic properties for the mixtures at the various temperatures and pressures are determined using the volume adjusted Peng-Robinson (MPR) EoS (Péneloux et al., 1982) where, to account for the behaviour of the relevant mixtures, the mixing rule of Nishiumi et al. (Nishiumi et al., 1988) is applied. As part of these calculations the position of the thermodynamic state relative to the phase envelope in order to determine the fluid phase. The transport properties are calculated as a function of fluid density, temperature and composition using the NIST Thermophysical database (Lemmon et al., 2007).

The following describes the application of the flow model described above to a hypothetical pipeline network being considered in the UK involving the capture and the transportation of CO₂ with different impurities from various sources to a point sink. The results describe the impact of varying pipeline inlet compositions from two sources on the predicted inlet pressure and exit temperature for a desired delivery pressure. Furthermore, the impact of varying the inlet feed flowrate on the required inlet pressures will also be analysed.

3. RESULTS AND DISCUSSION

It is important to note that if CCS technology becomes widely deployed, the efficiencies offered by CO₂ capture and transport networks make their use more likely, as distinct from a number of single source-to-sink connections (Mac Dowell et al., 2011, Alhajaj et al., 2013). Moreover, owing to increasing penetration of intermittent renewable electricity generation into our energy landscape, the in-feed of CO₂ into these networks is likely to be characterised by transience, exacerbated by the operation of the capture plants to maximise profitability (Mac Dowell and Shah, 2013, Mac Dowell and Shah, 2015). The need to understand how these networks will behave under realistic conditions is a principle motivation of this study, given that the accurate prediction of the steady state flow is essential prior to any transient analysis. Figure 3 shows a detailed schematic of the CO₂ pipeline network being considered in this case study. The pipe segments are consecutively numbered from 1 to 7 beginning at the storage site. The network connects Cottam and West Burton coal power stations in North Yorkshire to Drax power station via Scunthorpe steel works. The Drax power station is connected to the main trunk pipeline via a 0.5 km long tie-in line. From this point the CO₂ mixture is transported to its point of sequestration, Morcambe South in the East Irish Sea via Hornsea and Carnforth.

For the sake of simplicity, only feeds from Cottam and Drax power stations producing respective CO₂ flowrates of 4.847 and 20.153 Mt y⁻¹ are considered in this study. No contribution from the remaining sources is assumed.

Table 1 shows the pipe segment overall dimensions including the average elevations. Table 2 presents the assumed values of the various parameters required for the calculation of the heat transfer coefficient using equation (12). The pipe is assumed to be made of carbon steel with a thermal conductivity and roughness of 40 W/(mK) and 0.05 mm respectively. A total of 100 equally spaced steps were used for the implicit Euler method along each section, which was found to provide sufficiently accurate results.

	Pipeline length (km)	Pipeline Internal Diameter (m)	Pipeline inclination (°)	Thickness (mm)
Pipe 1	15.266	1.143	0.086	20
Pipe 2	84.668	1.143	0.007	20
Pipe 3	35.640	1.143	0.055	20
Pipe 4	0.5	1.143	0	20
Pipe 5	45.770	1.143	0.006	20
Pipe 6	26.490	1.143	0.017	20
Pipe 7	7.235	0.889	0.929	20

Table 1: Pipeline characteristics used for the case study

Property	Value
λ_w (W m ⁻¹ K ⁻¹)	40
α_o (W m ⁻² K ⁻¹)	5
d_{soil} (m)	1.2
δ_{ins} (m)	0.05
λ_{soil} (W m ⁻¹ K ⁻¹)	1.21
λ_{ins} (W m ⁻¹ K ⁻¹)	0.058
T_{amb} (K)	288

Table 2: Thermal properties of insulation, soil and pipe wall (for equation 12) (Witkowski et al., 2013, Perry and Green, 1997)

Figure 3: Schematic representation of the pipeline network simulated

In this study, four scenarios are assumed:

1. both Cottam and Drax use a Post-combustion capture technology (representing the least number impurities for a commercial stream);
2. both Cottam and Drax use an Oxyfuel capture technology (most impurities for a commercial stream);
3. Drax uses an Oxyfuel capture technology and Cottam a Post-combustion;
4. Cottam uses Oxyfuel capture technology and Drax a Post-combustion capture technology

Table 3 presents the representative feed mass flow rates and compositions at Cottam and Drax power stations for each of the 4 scenarios outlined above. The purpose of this investigation is to use the steady state pipeline network model developed above to predict, for a given feed temperature of 300 K at Cottam and Drax power stations, the corresponding required feed inlet pressures to ensure the final delivery pressure of 90 bara at the sink point, Morcambe South for each of the 4 scenarios.

For all scenarios considered, the delivered CO₂ mixture composition at the sink point is also determined. Such information is especially useful, given the established impact of CO₂ impurities on the type of pipeline steel employed in terms of resistance to propagating

factures (Mahgerefteh et al., 2012) and corrosion (Thomas, 2005) as well as storage performance in terms of injectivity and capacity (IEAGHG, 2011, Ziaabakhsh-Ganji and Kooi, 2014). Finally, the corresponding fluid pressures and temperature profiles along the main trunk pipeline are also presented for each of the four scenarios simulated.

Table 4 presents the predicted feed pressures required from Cottam and Drax power stations and delivery temperatures at Morcambe South for each of the four scenarios under consideration. Also shown is the composition of the delivered CO₂ stream at Morcambe South. These predictions were made after solving the steady-state flow model equations (1-6) with the appropriate boundary conditions (equations 10-12).

	Scenario 1 (Post-combustion)	Scenario 2 (Oxyfuel)	Scenario 3 (Drax: Oxyfuel; Cottam: Post combustion)	Scenario 4 (Drax: Post combustion Cottam: Oxyfuel)
Drax flowrate (Mt y⁻¹)	20.153	20.153	20.153	20.153
Cottam flowrate (Mt y⁻¹)	4.847	4.847	4.847	4.847
Drax composition (vol/vol)	CO ₂ – 0.998 N ₂ – 0.002	CO ₂ – 0.881 H ₂ O – 0.002 Ar – 0.057 N ₂ – 0.037 O ₂ – 0.023	CO ₂ – 0.881 H ₂ O – 0.002 Ar – 0.057 N ₂ – 0.037 O ₂ – 0.023	CO ₂ – 0.998 N ₂ – 0.002
Cottam composition (vol/vol)	CO ₂ – 0.998 N ₂ – 0.002	CO ₂ – 0.881 H ₂ O – 0.002 Ar – 0.057 N ₂ – 0.037 O ₂ – 0.023	CO ₂ – 0.998 N ₂ – 0.002	CO ₂ – 0.881 H ₂ O – 0.002 Ar – 0.057 N ₂ – 0.037 O ₂ – 0.023

Table 3: Feed flowrates and compositions for scenarios 1-4.

As may be observed, a greater amount of compression is required at both sources points when greater amounts of impurities are in the feed stream, in order to meet the required delivery pressure. However the difference is only of the order of *ca.* 1 bara between the four cases considered. Furthermore, the lower the percentage of impurities, the higher the exit temperature; albeit the differences once again only being marginal (*ca.* 2 K).

3.1. Pressure and temperature profiles along the network

Figures 4 and 5 show the respective pressure and temperature profiles along the length of the main trunk pipeline for each of the four scenarios simulated. Referring to Figure 4, the following observations may be made:

- I. The rate of drop in pressure from the feed to the delivery point is almost linear throughout;
- II. The additional feed flow from the Drax power station using the tie-line (Pipe 4) into the main trunk at the intersection between Pipe 5 and Pipe 3 results in an increase in the downstream rate of pressure drop;
- III. In general, increase in the number of impurities results in an increase in the drop in pressure along the pipeline. Scenarios 1 and 4 produce almost identical pressure profiles despite the fact that the feed composition from Cottam power station is very different in either case (Scenario 1: Post- combustion; Scenario 4; Oxyfuel). This is due to the much higher feed flowrate from Drax power station (ca. 20 Mt y⁻¹) as compared to Cottam power station (ca. 4 Mt y⁻¹) thus overshadowing the impact of the latter;
- IV. As expected, all the pressure profiles converge to the delivery pressure of 90 bara at the downstream end of Pipe 1.

	Scenario 1 (Post-combustion)	Scenario 2 (Oxyfuel)	Scenario 3 (Drax: Oxyfuel Cottam: Post-combustion)	Scenario 4 (Drax: Post-combustion Cottam: Oxyfuel)
Drax inlet pressure (bara)	105.3	106.8	106.3	105.4
Cottam inlet pressure (bara)	107.3	108.4	108.3	107.0
Delivery composition at Morcambe South (vol/vol)	CO ₂ – 0.998 N ₂ – 0.002	CO ₂ – 0.881 H ₂ O – 0.002 Ar – 0.057 N ₂ – 0.037 O ₂ – 0.023	CO ₂ – 0.904 H ₂ O – 0.002 Ar – 0.046 N ₂ – 0.030 O ₂ – 0.018	CO ₂ – 0.976 H ₂ O – trace Ar – 0.011 N ₂ – 0.009 O ₂ – 0.004
Delivery temperature at Morcambe South (K)	297.9	295.2	296.6	297.8

Table 4: Predicted required feed pressures and delivery compositions for Scenarios 1-4.

Turning to Figure 5, the following observations may be made:

- I. Similar to the pressure profiles in Figure 4, the rate of temperature drop from the feed to the delivery point is almost linear;
- II. At the inlet point of Pipe 3 (*ca.* 69 km) a rise in the temperature is observed in all cases. This is due to the incoming warmer feed stream from the Drax power station.
- III. In general, the temperatures are seen to decrease from an initial value of *ca.* 303 K;
- IV. The higher the level of impurities, the greater is the drop in temperature. It is also observed that the rate of temperature drop for Scenario 1 and 4 are similar. The explanation for this is the same as point 3 for Figure 4.

Figure 4: Variation of fluid pressure along main trunk line (excluding Pipe 4 in Figure 3).

3.2. Impact of a change in the inlet feed flowrate from a branch line on pipeline network

In order to investigate the impact of a change in a CO₂ source mass flow rate on the overall behaviour of the network, Scenario 3 (see Table 3) is repeated assuming a 10 % fall (ramp-down) and increase (ramp-up) in the flowrate from the Drax power station. In practice, such changes in the CO₂ flowrate may for example occur due to a drop in electricity demand during night time operation.

Table 5 shows the corresponding predicted feed pressures from Drax and Cottam power stations in order to maintain the delivery pressure of 90 bara at the injection site, Morcambe South. Also included are the simulated injection compositions and temperatures at the same location. As it may be observed, a 10% ramping down of the feed flow rate from the Drax power station will require the feed pressures from Drax and Cottam to drop to 104.6 bara and 106.6 bara respectively. The corresponding pressures as a result of a 10% ramping up of the flowrate at the Drax power station are 108.2 bara and 110.1 bara respectively. Furthermore, the CO₂ composition at the injection site is only marginally affected due to the changes in Drax feed flow rate. The average deviation in delivery composition from Scenario 3 is *ca.*

1.15 % for the ramp-down case and *ca.* 1.82 % for the ramp-up case. It is noteworthy that the purity of CO₂ in the ramp-down case at the delivery location is the highest. The exit temperatures are also observed to decrease with an increase in the flowrate from Drax power station.

Figure 5: Variation of fluid temperature along main trunk line (excluding Pipe 4 in Figure 3).

Figure 6 shows the variation of the fluid pressure along the main trunk pipeline for Scenario 3, ramp-up and ramp-down simulations respectively. As it may be observed, in general the higher the flowrate from Drax power station the greater is the observed pressure drop. It should also be noted that all pressures are observed to converge at the required delivery pressure of 90 bara at the downstream end of Pipe 1.

Figure 6: Variation of fluid pressure along main trunk pipeline for a 10 % ramp-up and ramp-down in the CO₂ flowrate from Drax power station for Scenario 3.

3.3. Impact of equation of state on predictions

In order to establish the influence of the choice of EoS on the predictions of the overall behaviour of the network, the simulation of Scenario 3 (see Table 6) is repeated with the GERG-EoS as implemented in REFPROP (Lemmon et al., 2007).

As may be observed in Table 6, the predictions obtained using the two EoS show almost identical inlet pressures. The delivery temperatures however are observed to differ slightly. Figure 7 shows the variation of temperature along the main trunk pipeline, it can clearly be seen that the change in EoS result in only very minor differences in the profile.

	Scenario 3	Ramp-down	Ramp-up
Drax inlet pressure (bara)	106.3 (20.153 Mt y ⁻¹)	104.6 (18.14 Mt y ⁻¹)	108.2 (22.17 Mt y ⁻¹)
Cottam inlet pressure (bara)	108.3 (4.84 Mt y ⁻¹)	106.6 (4.84 Mt y ⁻¹)	110.1 (4.84 Mt y ⁻¹)
Delivery composition at Morcambe South (vol/vol)	CO ₂ – 0.904 H ₂ O – 0.002 Ar – 0.046 N ₂ – 0.030 O ₂ – 0.018	CO ₂ – 0.906 H ₂ O – 0.002 Ar – 0.045 N ₂ – 0.029 O ₂ – 0.018	CO ₂ – 0.902 H ₂ O – 0.002 Ar – 0.046 N ₂ – 0.031 O ₂ – 0.019
Delivery temperature at Morcambe South (vol/vol)	296.6	297.0	296.1

Table 5: Predicted required feed pressures and delivery compositions for a 10 % ramp up and ramp down in the Drax power station feed flowrate for Scenario 3.

	MPR	GERG
Drax inlet pressure (bara)	106.3	106.3
Cottam inlet pressure (bara)	108.3	108.3
Delivery temperature at Morcambe South (vol/vol)	296.6	296.4

Table 6: Predicted required feed pressures and delivery conditions for Scenario 3 using the MPR and GERG EoS respectively.

4. CONCLUSION

It is increasingly recognised that the success of CCS in reducing global warming relies on the capturing of CO₂ from additional major emission sources such as steel works or cement manufacturing industries apart from fossil fuel power plants. An integrated pipeline network capable of capturing CO₂ from these various emission sources for injection into the storage reservoir clearly represents the most practical and economic mode of operation for such a system.

Typical data required for the design of such networks are the fluid phase, temperature, pressure drop, mass flow rate and the CO₂ composition at any point along the pipeline network as well as those delivered to the storage site. Knowledge of the CO₂ composition following the mixing of the various captured streams is especially important given their established impact on the CO₂ phase behaviour and hence the compressor power requirements, pipeline material propensity to fracture propagation and corrosion. Impurities also impact the reservoir performance in terms of injectivity and capacity through geochemical interactions with the porous structure.

In this paper a rigorous steady state model was applied to a realistic CCS pipeline network system in the UK, collecting CO₂ from several emitters followed by injection into an offshore reservoir via a main trunk pipeline. The test case examined involved the required feed source flow rates in order to ensure a fixed delivery pressure of 90 bar at the point of injection into the storage reservoir.

While there is currently no measured data available with which to validate the model, the predictions obtained from it show the expected trends. The results of the case study presented show that for the network investigated the differing stream compositions had a marginal impact on the pressure drop. It was also found that pressure drops predicted using the MPR EoS show negligible differences with those obtained using the reference GERG EoS.

Figure 7: Variation of fluid temperature along main trunk pipeline predicted using the MPR and GERG EoS for Scenario 3.

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