Goldfields Gas Pipeline
Access Arrangement 2015 – 2019

Comments
on
Pipeline Capacity Modeling
and
the Impact of Changing Gas Quality

Draft: 29 May 2016

[redacted]

Sleeman Consulting

Contents

1 BACKGROUND

1.1 In August 2014 Goldfields Gas Transmission Pty Ltd (**GGT**) submitted to the Western Australian Economic Regulation Authority (**ERA**) proposed revisions to the Access Arrangement for the Goldfields Gas Pipeline (**GGP**) for the period 2015 to 2019, inclusive. The proposed revisions included an upward reset (from 35.5 MJ/m^3 to 37.0 MJ/m^3) of the minimum acceptable Higher Heating Value (**HHV**) for gas to be transported in the GGP. GGT stated[1] that "Virtually all gas transportation agreements … require that gas delivered into the [GGP] have a [HHV] exceeding 37.0 MJ/m^3".

1.2 In December 2015 the ERA published its Draft Decision on the proposed revisions to the Access Arrangement for the GGP. Among other things, the ERA[2]:

i) rejected the proposed upward reset of the minimum acceptable HHV;

ii) accepted GGT's forecast of reserved pipeline capacity (of around 105 TJ/d); and

iii) noted that, since the overall capacity of the GGP is 109 TJ/d, spare capacity of approximately 4 TJ/d exists.

1.3 In February 2016 GGT submitted to the ERA its Response to the ERA's Draft Decision (**Response**). In the Response GGT noted that:

i) in March 2015, the Western Australian Government promulgated[3] a Reference Specification for the GGP, incorporating a minimum HHV of 35.5 MJ/m^3. Pursuant to the *Gas Supply (Gas Quality Specifications) Act, 2009*, the Reference Specification overrides gas quality related provisions of contracts for use of the GGP.

ii) if gas with a HHV as low as 35.5 MJ/m^3 is to be transported in the GGP then the capacity of the GGP will be reduced. GGT stated that the revised capacity is 102.5 TJ/d.

1.4 I have been asked by the ERA to:

i) provide advice on whether GGT's methodology for calculating pipeline capacity is reasonable, or whether an alternative approach would be better; and

ii) to confirm that modeling inputs, assumptions and outputs are reasonable and relate specifically to the regulated sections of the GGP.

1.5 My findings are set out in the following sections of this Report.

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1 See paragraph 2.1.5 page 9 of *Access Arrangement Revision Proposal – Supporting Information*, 15 August 2014.

2 See paragraphs 172 and 173, page 38 of Draft Decision.

3 See page 15 of Response.

2 MODELING METHODOLOGY

2.1 To ascertain whether GGT's modeling methodology is reasonable I have:

i) discussed the modeling methodology with representatives of the APA Group's "Infrastructure Strategy and Engineering Division", which undertakes pipeline capacity modeling on behalf of GGT; and

ii) reviewed available documentation, including material provided by the APA Group representatives.

2.2 Modeling of the capacity of the GGP is carried out by APA using the Synergi™ Pipeline Simulator, a tool that allows transient flow simulation of gas pipeline networks.

2.3 The Synergi™ Pipeline Simulator allows the capacity and performance of the GGP to be accurately predicted for scenarios of interest, including the impact of changes in the specification of gas to be transported.

2.4 For the purpose of determining the capacity of the GGP when transporting gas with different HHVs the modeling methodology adopted by APA may be characterised as a three-stage process, as set out in following paragraphs.

2.5 Stage 1 involved establishment of a calibrated pipeline model to accurately reflect the gas transportation capability of the GGP. This entailed:

2.5.1 populating the Synergi™ Pipeline Simulator with actual physical data for the GGP, including but not limited to:

i) details of pipeline section lengths, internal diameters and pressure limitations;

ii) compressor locations, power and efficiency; and

iii) pipeline operating (ground) temperature.

2.5.2 running the 'populated' model with actual, historic gas flow information, and comparing modeled results, namely pipeline pressure profile, with actual, historic pipeline performance data.

2.5.3 calibrating the model so that modeled results aligned with actual, historic performance data. This was achieved by adjusting the assumed roughness of the internal pipeline surfaces (which affect friction and hence pressure loss) until alignment was achieved. The calibrated model of the GGP utilises a roughness measure of 7 micron.

2.6 Stage 2 involved running the calibrated model on the basis of contracted commitments for covered capacity (rather than actual historic gas flows), assumed HHV[4], for which the capacity of the GGP is being determined, (rather than actual, historic HHV) and excluding any assets that are not part of the covered pipeline. Since the underlying model had been accurately calibrated,

[4] Various scenarios were investigated including with HHVs of 35.5, 37.0 and 39.0 MJ/m^3. The purpose of each scenario is to investigate the capacity of the GGP when transporting gas of that assumed quality.

these predictive model runs provide an accurate indication of pipeline performance.

2.7 The Stage 2 GGP model runs confirmed that the GGP, if transporting gas with a HHV of 35.5 MJ/m^3, would be capable of meeting contracted commitments. Further, since minimum pressure requirements at all gas delivery points were exceeded, it was evident that the pipeline would have capacity to transport quantities of gas in excess of those contracted commitments. Spare capacity also exists if gas to be transported is assumed to have a HHV higher than 35.5 MJ/m^3.

2.8 Stage 3 involved carrying out further runs of the GGP pipeline model (as set up for Stage 2 above) to quantify how much spare capacity would be available when transporting gas with various HHVs (including 35.5, 37.0 and 39.0 MJ/m^3). This involved:

2.8.1 addition of an incremental, ‘test’ gas load at selected delivery point(s), with that load progressively increased until a pipeline operating constraint (minimum pressure at any location) was reached. The sum of all loads (contracted and incremental) represents the full capacity of the GGP for that operating scenario and load distribution.

2.8.2 APA undertook the above-described assessment for two alternative test load locations, namely the Newman offtake (being the end of the 400 mm diameter pipeline section) and Kalgoorlie (being the end of the 300 mm diameter pipeline section). The need to investigate capacity at multiple locations arises since, the greater the distance over which the test gas load is to be transported, the greater will be its impact upon pressure loss through the pipeline. That is, the ultimate capacity of the GGP is dependent upon the location, or distribution, of loads along its length.

2.9 Having regard for the location of contracted loads, APA concluded from the Stage 3 analyses that the capacity of the GGP when transporting gas with a HHV of 35.5 MJ/m^3 [or 37.0 MJ/m^3] is:

i) 102.0 TJ/d [or 106.9 TJ/d] if the incremental load is at Kalgoorlie; or

ii) 103.7 TJ/d [or 109.8 TJ/d] if the incremental load is at the Newman offtake.

2.10 I consider the methodology adopted for calculating the capacity of the GGP to be sound in that APA has utilised a high-quality, properly configured and calibrated model in its calculation of the capacity of the GGP. The key potential issue with the modeling process, addressed in Section 3 of this Report, relates to specification scenarios to be investigated (that is, selection of input data for the model).

3 INPUTS, ASSUMPTIONS AND OUTPUTS

3.1 With the exception of gas quality related parameters, inputs used by APA in modeling the future capacity of the GGP reflect actual technical/commercial details (such as lengths, pressures or MDQs). These inputs are matters of fact and, based upon available information, have been properly utilised by APA. I have not however undertaken a detailed audit of APA's modeling to confirm this is the case.

3.2 Regarding gas quality related parameters, in my opinion there are two matters, as follow, that need to be considered:

3.2.1 First, consideration needs to given as to whether it is appropriate to undertake capacity modeling on the basis of a HHV of 35.5 MJ/m^3, rather than some other figure. I consider this to be a matter to be determined by the ERA, and offer comments below that may assist the ERA with its deliberation.

3.2.2 Second, in investigating the impact of changes in the HHV of gas that might enter the GGP, APA has changed the HHV used in the Synergi^{TM} Pipeline Simulator and has made simplified provision[5] for other gas composition-related factors that may simultaneously change. Other factors that may change are the Relative Density of the gas and, as the Relative Density changes, the compressibility of the gas and the friction factor associated with flow of the gas. I have investigated below whether this simplification may render modeled outcomes questionable.

3.3 Regarding the adoption for modeling purposes of a HHV of 35.5 MJ/m^3:

3.3.1 A HHV of 35.5 MJ/m^3 represents a worst-case outlook in that it is the lowest HHV that, pursuant to the *Gas Quality Specifications*[6], GGT can be obliged[7] to transport in the GGP.

3.3.2 GGT contends that the capacity of the GGP should be determined using the worst-case HHV outlook as GGT cannot refuse to transport gas of this quality, nor will compensation be payable for the consequent reduction in pipeline capacity.

3.3.3 I accept that the *Gas Quality Specifications* oblige GGT to accept delivery into the GGP of gas with a HHV as low as 35.5 MJ/m^3.

3.3.4 I note that gas with a HHV approaching 35.5 MJ/m^3 is already being delivered[8] into the Western Australian gas market, specifically, into the

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[5] In its "Response to Information Request ERA32", APA advised it adopted a Relative Density of [redacted] when modeling capacity with a HHV of 39.0 MJ/m^3, and a Relative Density of 0.60 when modeling capacity with a HHV of 35.5 MJ/m^3.

[6] I use the term "*Gas Quality Specifications*" as a reference to both the *Gas Supply (Gas Quality Specifications) Act, 2009* and the *Gas Supply (Gas Quality Specifications) Amendment Regulations 2015.*

[7] Gas of a lower HHV may be transported, subject to a pipeline impact agreement being in place to the satisfaction of GGT.

Dampier to Bunbury Pipeline (**DBP**). In all but extreme circumstances, Macedon gas will not enter the GGP since it is delivered into the DBP at a location some 86 km south of the point at which the DBP and the GGP are interconnected, and subsequently flows in a southerly direction as a comingled mixture with other gas in the DBP.

3.3.5 For the overall HHV of gas transported in the GGP to fall to 35.5 MJ/m^3 <u>all</u> gas entering the GGP (directly or from the DBP) would have to have a HHV at this worst-case level.

3.3.6 From a purely technical perspective, it is conceivable that all gas delivered into the GGP could have a HHV of 35.5 MJ/m^3.

3.3.7 However, gas presently[9] delivered into the Western Australian gas market has a HHV of the order of 38 to 39 MJ/m^3, as transported through the GGP, or 37.5 to 38 MJ/m^3, in the case of the DBP.

3.3.8 For a gas to have a HHV of 35.5 MJ/m^3 that gas would, as explained in Attachment One hereto, need to comprise predominantly methane and nitrogen, with only modest amounts of higher hydrocarbons (C2 and higher) and/or carbon dioxide.

3.3.9 On the basis of my knowledge and experience, I consider it unlikely that the specification of gas to be transported through the GGP will change markedly in the near-term. This is because:

i) the composition of gas from large reservoirs from which gas is sourced will change only marginally over the production life of each reservoir; and

ii) new sources of gas supply that will come on line in the near-term, namely Gorgon or Wheatstone, are expected[10] to have a HHV above 35.5 MJ/m^3 to comply with the gas quality requirement of the DBP, into which they will be delivered. Further, they will be supplied into the DBP to the south of the point at which the DBP and the GGP are interconnected.

3.4 Regarding the use of HHV for analysis purposes whilst ignoring other gas composition-related factors:

3.4.1 The interdependence between gas quality related factors is illustrated in Attachment One to this Report. Attachment One shows the HHV and Relative Densities of hypothetical mixes of methane, ethane, carbon dioxide and nitrogen.

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8 Macedon gas reportedly has a HHV of 35.68 MJ/m^3. See page 2 of letter dated 25 May 2005 from BHP Billiton Petroleum to the ERA, available at: https://www.erawa.com.au/cproot/3714/2/BHP-Submissions_re_DBNGP_Draft_Decision-confidential.pdf

9 From inspection of the “Gas Specification” page of the *Gas Bulletin Board WA*, available at: www.gbbwa.aemo.com.au/#reports/gasSpecification

10 For example, see Table 8, page 25 of “Review of Gas Specification for the Dampier to Bunbury Pipeline…”, MJ Kimber Consultants Pty Ltd, 22 February 2006, which estimated the HHV of Gorgon Gas to be above 37.0 MJ/m^3.

3.4.2 Attachment One also shows that a gas with a HHV as low as 35.5 MJ/m^3 will necessarily have a Relative Density less than 0.596, otherwise the legislated minimum Wobbe Index requirement (46.0 MJ/m^3) will be breached.

3.4.3 The relevance for capacity modeling of considering all gas quality related parameters, rather than just arbitrarily changing assumed HHV's, is outlined in Attachment Two to this Report.

3.4.4 As outlined in Attachment Two, the capacity of a gas pipeline in energy terms (ie TJ/d) is not just a function of the HHV of the gas being transported. Rather, capacity in energy terms is proportional to HHV divided by the square root of Relative Density x Compressibility x Friction Factor.

3.4.5 Attachment 2 also demonstrates that:

i) variations in the factors referred to in paragraph 3.4.4 above do to some extent offset one another; and

ii) ignoring factors other than HHV will, in my assessment, more likely than not result in modest understatement of the capacity related impact of a decline in HHV.

3.4.6 I also note that, given the range of possible gas compositions and gas quality related parameters – only a cross-section of which is presented in Attachment One, it would be impractical to attempt to address all possible scenarios and outcomes.

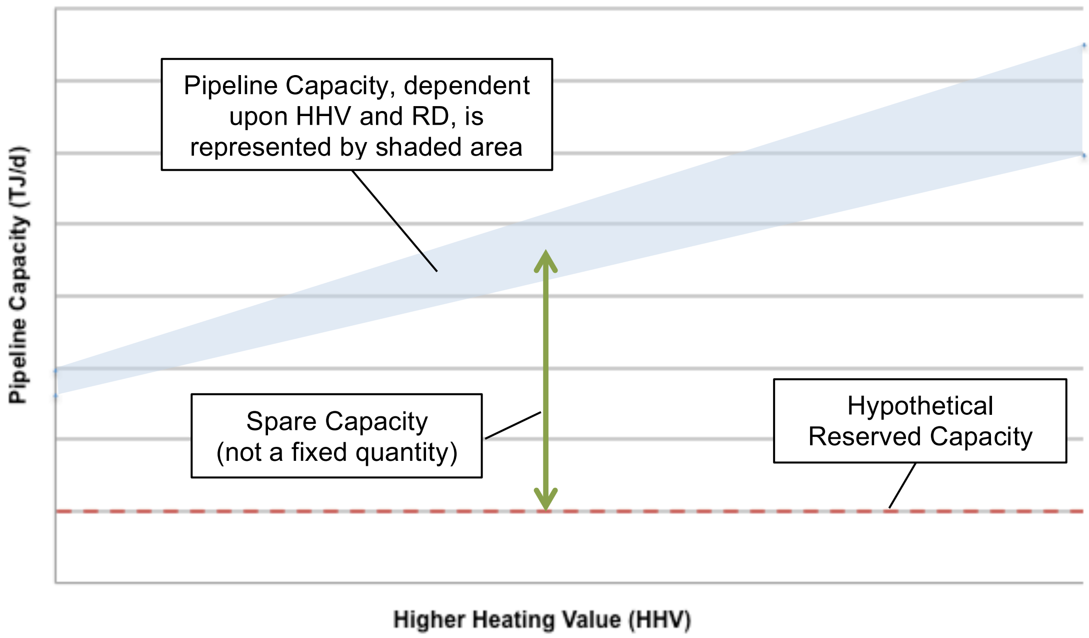
3.4.7 Accordingly, while it could be argued there is modest scope for refinement of APA's modeling inputs [11] (through more detailed consideration of gas quality parameters other than just HHV), I consider the existing approach (use of selected HHV – Relative Density scenarios) gives outputs that are reasonably indicative of the impact of changing HHV. A more rigorous approach may tend to produce outputs that are scenario specific, and therefore not generally applicable.

[11] For avoidance of doubt, I am not referring here to the subject matter addressed in section 3.3 of this Report. I am saying that for a given input data set, model outputs are reasonable. Selection of the input data set (specifically, HHV) upon which pipeline capacity modeling should be carried out is a matter for determination by the ERA.

4 POSSIBLE ALTERNATIVE APPROACH

4.1 As set out in Section 4 of this Report changes in the composition of a gas, and hence its HHV, will have an impact upon the ultimate capacity of the pipeline through which the gas is transported. This relationship is illustrated in Figure 1.

Figure 1: Illustrative Impact of HHV Changes on Pipeline Capacity



4.2 I agree that transportation of gas with a HHV lower than the level previously adopted for planning purposes will reduce the capacity of the GGP (in TJ/d terms).

4.3 Based upon my knowledge and experience I consider the following may be worthy of future consideration:

i) the capacity of the GGP could be determined on the basis of a clearly specified gas quality, potentially reflecting the average quality of gas it is anticipated will be transported through the GGP; and

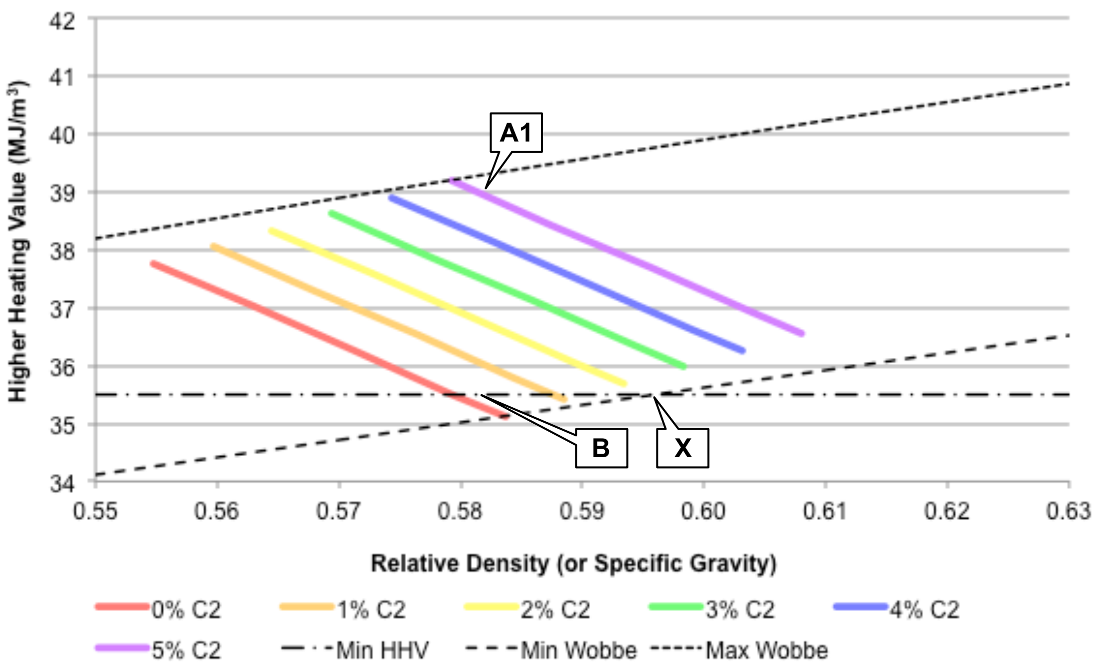
ii) a mechanism could be formulated whereby each user's capacity reservation(s) and applicable tariffs are adjusted to reflect the quality of gas actually transported on their behalf. This approach would ensure users pay for volumetric capacity that must be used to transport their gas.

ATTACHMENT ONE

A1 This Attachment outlines a number of practical considerations regarding gas quality, particularly HHV.

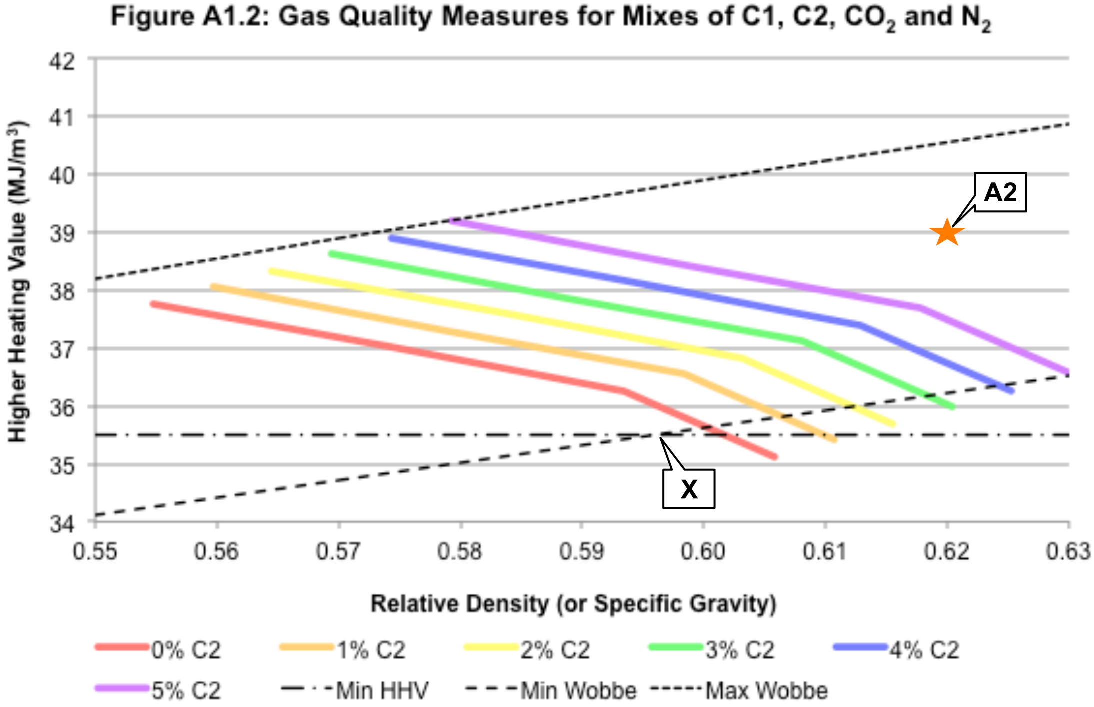
A2 Figure A1.1 illustrates the impact upon HHV and Relative Density of adding nitrogen to mixes of methane (**C1**) and ethane (**C2**). The left most line (in red) represents a mix containing no ethane. The right most line (violet) represents a mix containing 5% ethane. Moving from left to right along any line corresponds with the percentage nitrogen being raised from 0% to 7% (being the maximum allowable level of inert gases). As the percentage of ethane and/or nitrogen is increased, the percentage of methane is correspondingly reduced.

Figure A1.1: Gas Quality Measures for Mixes of C1, C2 and N_2



A3 Figure A1.2 illustrates the impact upon HHV and Relative Density of adding, first, carbon dioxide (to the maximum allowable level of 4%) and, then, nitrogen (to a maximum total inert gas level of 7%) to mixes of methane and ethane. The left most line (in red) represents a mix containing no ethane. Moving from left to right along any line corresponds with the addition of carbon dioxide then (at the point where each line bends) nitrogen to the mix. The bend in the lines reflects the fact that carbon dioxide has a 50% higher relative density than nitrogen, so addition of carbon dioxide has a more marked impact upon the Relative Density of the mix.

A4 Figures A1.1 and A1.2 also both contain lines representing HHV and Wobbe Index limits. The maximum HHV constraint is not shown as it is off the scale of the Figures and is not relevant to the subject matter of this Report.



A5 A number of relevant observations, as summarised below, may be drawn from consideration of Figures A1.1 and A1.2:

i) For a gas to have a HHV of 35.5 MJ/m^3 without breaching the minimum Wobbe Index requirement, that gas will need to comprise predominantly methane and nitrogen, with only modest amounts of higher hydrocarbons (C2 and higher) and/or carbon dioxide. Addition of higher hydrocarbons or carbon dioxide will result in the constraining gas quality criterion being minimum Wobbe Index, not minimum HHV.

ii) Following on from point 1) above, a gas with a HHV of 35.5 MJ/m^3 will have a Relative Density <u>less than</u> 0.596, corresponding with compositions to the left of the point marked 'X' in Figures A1.1 and A1.2.

iii) Gas with a HHV of 39.0 MJ/m^3 will necessarily have a Relative Density higher than approximately 0.575.

A6 The points marked 'A1', 'A2' and 'B' in Figures A1.1 and A1.2 are referred to in Attachment Two.

Attachment Two

Indicative Impact of Changed HHV

1. General Equation for Flow of Gas in a Pipeline

The following is a typical, reliable formula for determination of the volumetric capacity of a gas pipeline:

$$Q = 0.0011494\,\frac{T_s}{P_s}\sqrt{\frac{P_i^2 - P_o^2}{LGT_fZf}}\,D^5$$

where: Q is the gas flow (standard m^3/day)

T_s is standard temperature (288.15°Kelvin)

P_s is standard pressure (101.325 kPa)

P_i is the pressure of gas into the pipeline (kPa absolute)

P_o is the pressure of gas out of the pipeline (kPa absolute)

L is the length of the pipeline (km)

G is the Relative Density (or Specific Gravity) of gas being transported

T_f is the average temperature of gas being transported (°Kelvin)

Z is the gas compressibility factor at flowing temperature and pressure

f is the Darcy-Weisbach friction factor

The formula gives the capacity of a gas pipeline in standard m^3/day.

2. Pipeline Capacity in Energy Terms

Pipeline capacity in energy terms may be determined as the product of the capacity in standard m^3/day and the Higher Heating Value, or HHV, of the gas (MJ/m^3). Thus, pipeline $Capacity$ in MJ/day is:

$$Capacity = HHV \times 0.0011494\,\frac{T_s}{P_s}\sqrt{\frac{P_i^2 - P_o^2}{LGT_fZf}}\,D^5$$

3. Impact on Pipeline Capacity of Changing Gas Quality

Simple rearrangement of the formula set out in section 2 above, to group (in blue below) those factors that are sensitive to changes of gas quality, gives:

$$Capacity = \frac{\boldsymbol{HHV}}{\sqrt{\boldsymbol{GZf}}} \times 0.0011494\,\frac{T_s}{P_s}\sqrt{\frac{P_i^2 - P_o^2}{LT_f}}\,D^5$$

Thus, the impact upon pipeline capacity of changes to the composition (and hence HHV) of a gas will be proportional to the HHV of the gas divided by the square root of Relative Density x Compressibility x Friction Factor.

4. Quantification of Impact

APA has calculated the impact of changing HHV on the capacity of the GGP by changing only the HHV input used for modeling. Changes to Relative Density, and consequential changes to Compressibility and Friction Factor, have been ignored. Since the changes that APA has ignored will tend to offset one another[12] I have carried out the following simulations to ascertain whether the potential error of APA's simplified approach is material.

	Scenario 1 Relative Density unchanged	Scenario 2 Transition from 'rich' to 'lean' gas	Scenario 3 Transition from 'very rich' to 'lean' gas
Historic basis, example	Point A1[13], Fig. A1.1	Point A2[14], Fig. A2.2	(Not in Figures[15])
HHV MJ/m^3	39.0	39.0	39.0
Relative Density, G	0.5813	0.620	0.640
Compressibility, Z (est[16])	0.863	0.845	0.834
Friction Factor, f[17]	0.0096	0.0096	0.0096
Flow measure, $HHV/(ZGf)^{0.5}$	562	550	545
Low HHV, example	Point B[18] on Figures A1.1 and A1.2		
HHV MJ/m^3	35.5		
Relative Density, G	0.5813		
Compressibility, Z (est[16])	0.869		
Friction Factor, f[17]	0.0096		
Flow measure, $HHV/(ZGf)^{0.5}$	510		
Percentage Changes: Historic HHV to Low HHV			
Change in HHV	-9.0%	-9.0%	-9.0%
Change in Flow Measure	-9.3%	-7.3%	-6.4%
APA Modeled capacity change[19]	-6.0% to [redacted]		

I conclude that the modeling approach adopted by APA (that is, changing HHV with a simplifying assumption regarding Relative Density) provides a fair and reasonable indication of the impact upon pipeline capacity of changes to the HHV of gas being transported.

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12 All else being equal, changes to Relative Density will result in inverse changes to both Compressibility and Friction Factor

13 Indicatively 94.5% methane, 5% ethane, 0.53% nitrogen.

14 Indicatively 88.64% methane, 5.9% ethane, 1.7% propane, 3% nitrogen, 0.76% carbon dioxide.

15 Indicatively 89.18% methane, 5.0% ethane, 1.0% propane, 0.5% butane, 0.25% higher hydrocarbons, 0.30% nitrogen, 3.77% carbon dioxide.

16 Compressibility is also dependent upon the flowing temperature and average pressure of gas through the pipeline. I have taken this into account in calculation of estimated, representative Compressibility figures.

17 Friction Factor is a function of pipeline diameter, pipeline roughness and 'Reynolds Number'. Reynolds Number is dependent, among other things, upon Relative Density. I have taken this into account in calculation of an estimated, representative Friction Factor.

18 Indicatively methane 93.62%, ethane 0.22%, nitrogen 6.16%

19 The 6% figure is based upon capacity falling from 109 TJ/d to 102.5 TJ/d, as set out in footnote 94 on page 107 of the Response, but ignoring relocation (if any) of offtake MDQs. The higher figure is based upon information provided by APA in its "Response to Information Request ERA32".