IBP1178_15

COMMISSIONING OF THE ANGLO AMERICAN MINAS RIO IRON CONCENTRATE PIPELINE

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Abstract

The Anglo American Minas Rio Pipeline carries iron concentrate 529 km from a mine in the Brazilian state of Minas Gerais to the ocean port of Açu near Campos on the Atlantic coast of the state of Rio de Janeiro. The project was completed and started up in 2014 and is the longest distance operating slurry pipeline in the world. This work describes the pipeline system and its commissioning.

The system will transport 24.5 million dry tonnes of iron concentrate annually expandable to at least 26.5 million tonnes through a 26/24 inch pipeline. Two large positive displacement pump stations are needed to move the slurry, additionally other monitoring and pressure control stations are used to control the slurry as it moves along the varying pipeline terrain.

The project contains some special design concepts that are discussed, such as laboratory testing of slurry during design and commissioning, hydraulic modeling, operational philosophy, slack flow control, internal and external corrosion control, automation, telecommunications, and mechanical equipment.

1. Introduction

The Anglo American Minas Rio Pipeline carries iron concentrate 529 km from a mine in the Brazilian state of Minas Gerais near Conceção do Mato Dentro to the Atlantic coast ocean port of Açu near Campos and São João da Barra in the state of Rio de Janeiro.

Conceptual engineering for the project began in mid 2005 and basic engineering was begun by mid 2006. The pipeline system introduced the first slurry batch on August 20, 2014 and is currently the longest distance operating slurry pipeline in the world.

When at final capacity, the system will transport 24.5 million dry tonnes of iron concentrate annually expandable to at least 26.5 million tonnes through a single 26/24 inch pipeline. Two large positive displacement pump stations are needed to move the slurry, additionally other monitoring and pressure control stations are used to control the slurry as it moves along the varying pipeline terrain.

This work discusses the commissioning period pumping activities of the period August 2014 to February 2015. It also assists in documenting the design of the longest and highest tonne-km slurry pipeline transportation system ever constructed.

As shown in figure 1, the pipeline passed through the states of Minas Gerais and Rio de Janeiro. During this passage, twenty eight administrative districts or "Prefeituras" are crossed; each requiring special attention to the needs of its own community. After the construction period has been completed and the pipeline started up it will operate safely, efficiently, quietly and reliably for its complete life.

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Figure 1 The Anglo American Minas Rio slurry pipeline

2. Transported Product

2.1 Laboratory Assessment

During the design of the pipeline, extensive laboratory testing was carried out in order to establish the expected slurry behavior with lime and other non-toxic additives to favorably affect the slurry and to control its corrosive and rheological properties. Table 1 shows some of the results of that work used in designing the pipeline. Additionally corrosion tests, settling and other specialty slurry tests were performed, in order to establish steel corrosion rates, maximum pipeline slopes, shutdown and restart characteristics, particle size distributions and additives necessary for both slurry and water. This information was integrated into the pipeline design.

2.2 Commissioning Slurry Properties

During the commissioning period, a range of slurry properties were produced by the beneficiation plant. This is normal during commissioning programs. Slurry properties were tested and when satisfactory, the slurry was released for pumping.

Table 1 Typical Commissioning Slurry Properties

	C_w % (note 1)	δ_s	$Ø_s$	V_{rs}	η(cp)	η/μ	τ_y
Design Slurry (note 2)							
• High	72	2.39	0.344	0.523	11.19	12.56	11.57
• Normal	70	2.25	0.322	0.475	8.85	9.95	7.64
• Low	68	2.18	0.302	0.433	7.21	8.10	5.07
Commissioning Slurry							
• Typical Range	varies	2.0 to 2.25	varies	varies	5 to 10	-	5 to 25

Notes:

(1) C_w – Concentration by weight
$Ø_s$ – Saturated Volume Fraction
V_{rs} – Saturated Volume Ratio
η - Viscosity (cp)
η/μ - Reduced Viscosity
τ_y – Bingham Yield Stress (dynes/cm^2)
Δ_s – Saturated Solids Specific Gravity
δ – Slurry Specific Gravity

(2) Δ_s – Solids Specific Gravity 4.9

(3) pH range – 10.3 to 10.8

(4) Temperature 25°C

The slurry particle size distribution for the pipeline project limits the top-size to 100% less than 212 microns, no more than 1.5 % greater than 74 microns and at least 86% of the material less than 44 microns.
Corrosion tests indicated that the design corrosion rate should be 0.152 mm/y for the first 20 km and 0.102 mm/y for the remainder of the pipeline.

3. Slurry Pipeline System Description

3.1 Pipe and Pipeline

The 529 km buried un-lined pipeline is divided into two sections for purposes of pumping and operational control. Section 1 from pump station 1 (EB1) to pump station 2 (EB2) is 248 km in length, all 26 inch outside diameter pipe of varying wall thicknesses. The 281 km pipeline Section 2 begins at EB2 and ends at the Terminal tankage at Porto Açu. This section has both 24 and 26 inch outside diameter pipe, 166 km and 115 km respectively.

Table 2 Mainline Pipe Quantities

	Total (tonnes)	Pipe Wall Thickness Minimum - in (mm)	Maximum - in (mm)
Pipeline Section 1			
• 26 in (660 mm)	72,784	0.562 (14.3)	0.906 (23.0)
Pipeline Section 2			
• 26 in (660 mm)	25,116	0.406 (10.3)	0.906 (23.0)
• 24 in (610 mm)	32,562	0.438 (11.1)	0.969 (24.6)
Grand Total	130,462		

The pipeline has been constructed using the ASME B31.11-2002 Slurry Transportation Piping Systems code, as well as other referenced welding and fabrication codes. The pipeline has been constructed generally to not exceed 15% up or down slopes. The pipe is API 5L-X70 steel, externally protected by a 3 layer coating (3LPE) consisting of an internal layer of fusion bonded epoxy, followed by a copolymer adhesive, and an external layer of polyethylene (PE). The field joints are protected by shrink sleeves. The pipeline system is cathodically protected throughout using rectifiers.

The pipeline joints were 100% ultrasonically inspected during the construction period. The line was gage-pigged, hydrostatically tested, geometrically and ultrasonically pigged before slurry commissioning.

Both horizontal directionally drilled and tunnel installations were used throughout the pipeline for most river crossings and high points where large earth cuts would have been necessary to maintain the pipeline maximum slope restriction. Approximately 24,000,000 m3 of earth was moved during the right-of-way preparation.

During the construction period, geometric pigs were used to look for dents, pipe ovalization and weld intrusions. Those needing repair were repaired during construction.

Along the pipeline, 10 pressure monitoring and telecommunication repeater sites have been installed (PMS). They are powered sites supporting the fiber optic telecommunications system and are pressure monitoring points used for pipeline operations, and slack flow control. Additionally, corrosion monitoring instruments have been installed at these sites.

3.2 Pump Stations, Valve/Orifice Stations and Terminal

The two pump station pump houses needed to move the slurry are quite similar. EB1 has 8 mainline pumps installed with 7 operating and one spare, and EB2 has 10 installed with two spare pumps. EB2 has a somewhat more difficult duty than EB1. Each station has a control room, maintenance facilities and meeting rooms. EB2 has a cafeteria and local office facilities. Water for pipeline flushing at EB1 is supplied by the Beneficiation plant water system and stored in a flush water pond. At EB2 a dam has been constructed to hold 290,000 m3 of operational water storage and reserve for emergency pipeline Section 1 dumping.

The EB1 tanks are fed by a 1.8 km 24 in pipeline from the Beneficiation Plant. This feeder pipeline system consists of two 21.5 m diameter x 17 m high mixing tanks and two trains of centrifugal pumps, one operating and one stand-by train. Each train has two pumps in series.

EB1 has a 176 meter 26 inch outside diameter with a 0.406 in (639.78 mm) steel wall thickness test loop for checking slurry properties as needed prior and during operation. Instrumentation includes differential pressure taps, concentration gradient sample taps, density and flow meters.

An orifice station is located on the suction side of EB2, and used to control Section 1 line pressures during slurry batching periods. It contains 8 orifice loops with two ceramic orifices in each loop, each loop is designed for about 100 meters of water head loss (50 meters for each orifice). This station is used during the water/slurry batching and pipeline flushing to control slack line conditions as necessary. The slurry or water from Section 1 can be pumped directly to the suction of the EB2 pumps or diverted to the remix tank or water pond as necessary for the given operating conditions. Normal operation is to pump directly to the EB2 pumps suction header.

A valve station located at km 356.4 in Section 2 is used to control pipeline static pressure head when the pipeline is shut down. Additionally, the station is co-located with an orifice station of similar design to the EB2 station and also used to prevent slack flow in the up-stream portion of the section. The orifice loops are placed vertically in order to allow a single valve to engage and disengage each loop, and no piping flushing being necessary, and for easier orifice replacement.

Both orifice stations have their loops rubber lined, to prevent excessive wear at the wall of the pipe downstream of the orifices.

The Terminal at Porto Açu is comprised of a valve station and receiving tanks. The tankage feeds the co-located filter plant. Additionally, water/slurry receiving pond of 500,000 m^3 has been provided for use as necessary for emergency slurry dumping and water management as necessary.

3.3 Mainline Pumps

Mainline pumps are Geho TZPM 2000 triplex diaphragm type positive displacement pumps, each being driven by a variable frequency driven water cooled 2100 kW motor. Pump Station 1 has 8 installed and Pump Station 2 has 10 installed. The maximum continuous pump pressure allowed at EB1 is 176 kg/cm2 at a total flow rate of 2105 m3/h when 7 pumps are operating, and EB2 the maximum continuous pressure for 8 pumps operating is 180 kg/cm2 at a total flow rate of 2105 m3/h. Generally during the commissioning period the pumps have been operating at 94 to 95% volumetric efficiency. They can be operated to 60 rpm. Suction and discharge pressure pulsation dampeners have been charged, and are being optimized, based on pipeline suction and discharge pressures, flows and pump speeds. Their pressure charges are changed based on the pipeline discharge pressures and flow rates, generally they have been adjusted to 45 to 50 kg/cm2 during the initial period of lower flows and pressures. Suction dampeners are operating at 3 kg/cm2. A bladderless suction side air chamber is installed at each mainline pump suction inlet.

Pump discharge flange rating at both stations is 1500# ASME/ANSI class ratings. The suction side of EB1 is a 150# class rating, and the suction of the pumps at EB2 is 900# class rated, allowing EB2 to run connected to Section 1, thus allowing no oxygen to enter the line that could raise corrosion levels.

Figure 2 Pump Station 1 (EB1) four of 8 station pumps

3.4 Slurry Valves

The pipeline system has a total of 338 slurry valves of all sizes installed at its facilities. The general valve type is a sealed slide gate type for the 150# ASME/ANSI pressure classes and ball valves for the other pressure ratings. Eighteen 10 inch slurry check valves are used in the system for mainline pump discharge piping isolation. Valves when actuated are hydraulic operator equipped. Central hydraulic systems supply hydraulic energy and accumulated pressure to actuate valves several times if needed upon power failure.

Table 3 – System Slurry Valve Quantities

Valve Size (in)	ASME/ANSI Pressure Class	Valve Quantity
2	150	74
4	150	10
10	150	8
2	900	30
4	900	19
10	900	10
12	900	6
24	900	20
2	1500	43
3	1500	38

4	1500	14
10	1500	36
12	1500	8
24	1500	22
Total Slurry Valves		338

Figure 3 High and Low pressure valves

3.5 Agitators, Tanks and Slurry Charge Pumps

There are four slurry mixing tanks at EB1, one at EB2 and four at the Terminal. All are 21.5 m diameter and 17 m high. The active volume of each tank is approximately 5100 m3, resulting in about 2.5 hours of slurry flow available from each tank when full. Variable frequency motor driven agitators are 300 hp, operating at 15 rpm.

Two variable speed 710 kW centrifugal rubber lined slurry pumps (one operating and one standby are provided at each pump station. These pumps provide the minimum 3.5 kg/cm^2 needed for the mainline pumps to operate without cavitation when pumping from the slurry tanks or water from the pond.

Figure 4 Charge pumps and agitated tanks

3.6 SCADA System

A supervisory control and data acquisition (SCADA) system is provided to control and monitor the complete pipeline system from the main control room at EB1. Additionally, the same system has been installed at EB2 and the Valve/Orifice station (EV) to perform the identical functions. Some data is passed to the main Beneficiation Plant control room for monitoring. Sites monitored are the pump stations, 10 PMS stations, EV and Terminal.

The SCADA system is based on using Rockwell programmable controllers and master station software on a wide area network.

3.7 Telecommunication System

A 24-fiber all-dielectric fiber optic cable in a 40 mm HDPE SDR 11 smooth walled conduit has been placed along with the pipeline when it was installed. SDH based transmission hardware operating on a collapsed ring architecture supporting various protocols including high Gigabit Ethernet, voice and SCADA data has been installed. The SDH system uses 4 fibers, and repeater sites at each of the PMS sites for power and access to the SCADA hardware.

Video to selected sites has been provided for monitoring and security.

3.8 Leak Detection, Batch Interface Tracking and Slack Indication System

A pipeline leak detection system is installed to monitor the pipeline for leaks during normal operation. This pipeline graphic "Advisor" system is also used during batch operations to indicate batch locations, potential over-pressure and slack flow conditions.

4. Pipeline Commissioning

4.1 General

During the commissioning period the system was tested on water to determine the pipe wall roughness, tune the pump station performance and to do final cleaning and intelligent pig in-line pipeline inspection prior to the introduction of slurry.

4.2 Water Commissioning

Once the pre-operation testing had been completed, instruments calibrated and electrical equipment placed in service, the system was released to pump water. During this water pumping period, the final cleaning and inspection pigging was performed using the mainline pumps. After final pigging, pipeline roughness was established to be 0.00084 in (0.021 mm) throughout. The cleaning pig was tightly sized to pass the 24 in pipe and yet still clean the 26 in sections. As a result of the cleaning pig run, the roughness 0.00084 inches is near smooth pipe and consistent throughout the complete pipe sections. The roughness was measured on water at two flow rates 1460 and 2200 m3/h in Section 1 and 1900 m3/h in Section 2. Over one hour was needed to stabilize pressures at constant flow in each line section before readings were taken.

An ultrasonic instrumented pig was passed through the complete pipeline prior to pumping slurry. This ILI device collected absolute wall thickness data for corrosion base-line steel thickness on the as-constructed pipeline. Additionally, the inspection searched for other anomalies, to be addressed when the ILI device data was compiled.

When pumping water, a sodium sulfite oxygen scavenging solution is being injected to drop oxygen concentration levels.

4.3 Slurry Commissioning

Slurry testing was performed using the test loop at EB1 in the days preceding the decision to pump slurry in the mainline. The test loop roughness was shown to be 0.007 in using an equivalent length of pipe of 247.4 m. The initial slurry was of lower quality, but loop testing and lab tests indicated that the slurry met the minimum requirements for pumping. It was established that the 1826 m3/h would be the minimum flow rate for the 64% concentration, 4.6 solids specific gravity slurry. This would keep the solids velocity for the pipeline at or above the minimum acceptable 1.6 m/s.

Mainline commissioning on slurry began on August 20, 2014 at approximately 10:25am when the first slurry was introduced to EB. The slurry batch length was approximately 27 km (about 4.5 hours) in Section 1. Slurry was passed through the tank at EB2, and pumped on to the Terminal where it arrived on August 24, 2014 at 6:00am. There was no shutdown or stoppage of this batch during the transit period.

During the commissioning period many batches of slurry were pumped and analyzed. Figures 5 and 6 show slurry and water pressure head losses for the slurry pumped on those days. The figures show the steady state hydraulic grade line (HGL) for both water and slurry in the pipeline. The HGL is in meters of material at the particular position along the pipeline.

Figure 5 shows the "snapshot" of Batch 4-2015 in pipeline Section 1 with its head at km 191.3 and the batch tail at km 113.5. The flow rate during the measurement period was 1965 m3/h, yielding an average velocity of 1.79 m/s for the 68% solids by weight slurry.

Figure 6 shows Batch 7-2014 passing through Section 2. The slurry batch head is at km 408.4 and the tail is at km 356.4 entirely in the 24 in pipe section, no EV orifice loops are engaged. The flow rate at the time was 2100 m3/h at 67.9% solids, yielding a 2.19 m/s average velocity in the 24 in pipe and 1.85 m/s in the 26 in pipe.

During the commissioning period the slurry was stopped in the pipeline on several occasions for up to 8 hours, and restarted. Multiple batches have been placed in each section on many occasions.

Pump valve and diaphragm lives have not posed an operational problem and appear to be within expected lives. Agitators have been able to agitate the slurry in the tanks satisfactorily at EB1 and EB2.

Internal pipe corrosion monitoring is being carried out and data under review.

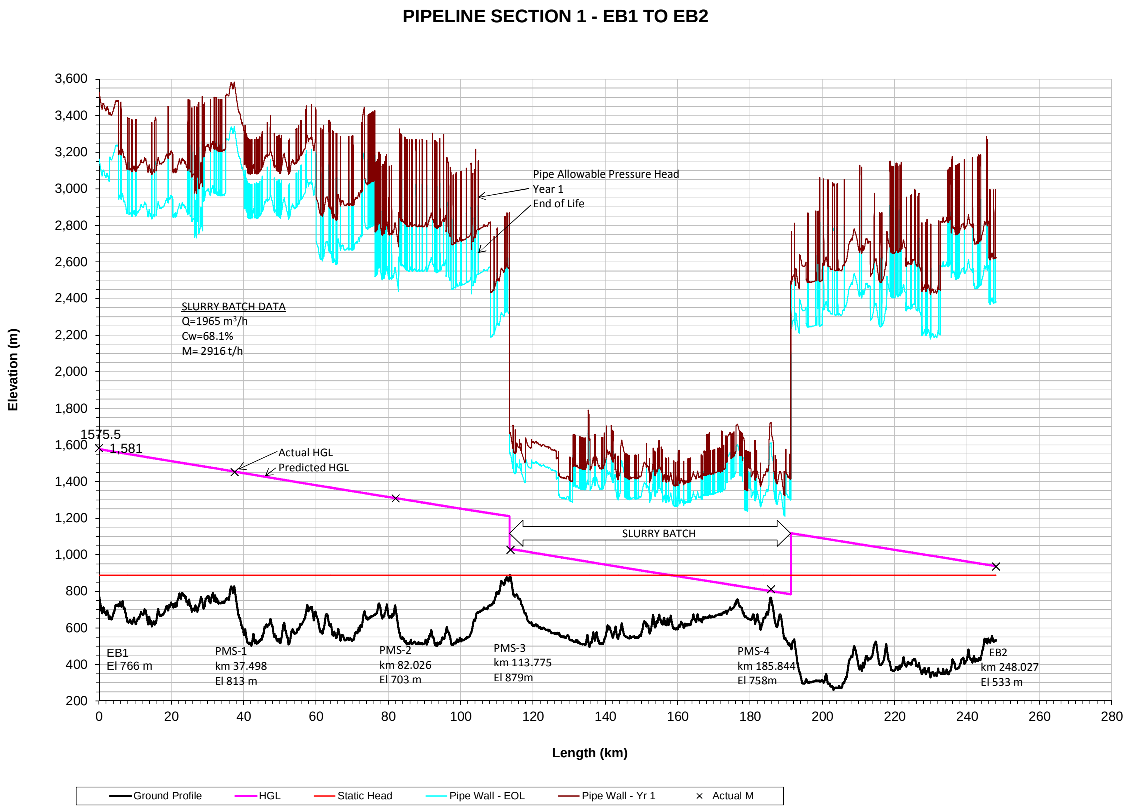

Figure 5 Section 1 Hydraulics EB1 to EB2 (Batch 04-2015)

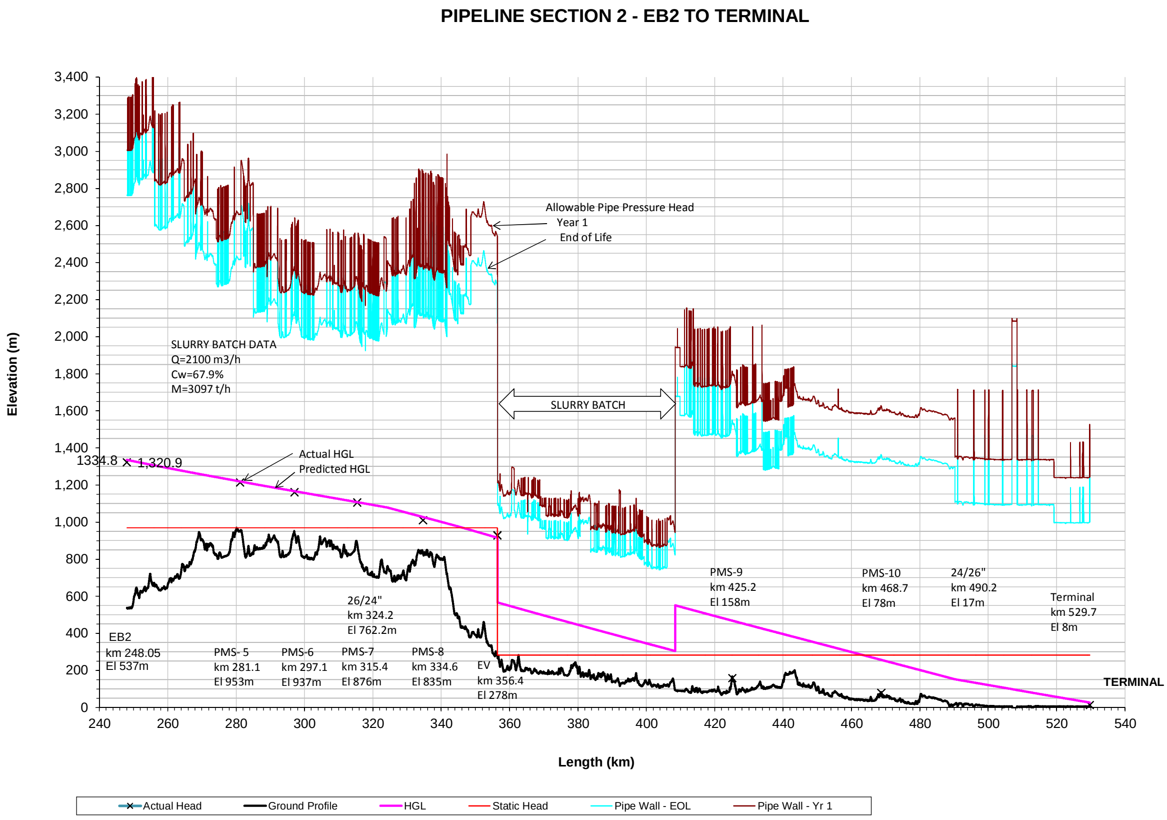

Figure 6 Section 2 Hydraulics EB2 to Terminal (Batch 07-2014)

5. Conclusions

The slurry pipeline has operated during the commissioning period, transporting the tonnages expected. During the continuing production ramp-up period additional data will continually be collected that will allow pumps, diaphragms, valves, agitators, orifices and other equipment performance assessments to be made. Additionally, slurry property optimization will continually be carried out.

6. Acknowledgements

We would like to thank Anglo American Minas Rio organization for allowing the presentation of this paper and inclusion in the proceedings.

7. References

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