IRON ORE SLURRY PIPELINES – PAST, PRESENT AND FUTURE

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ABSTRACT

The world's first long distance iron ore mineral slurry pipeline was built in Australia in 1967 for the Savage River magnetite concentrate mine in Tasmania. Since then, in the Australasian region, the following iron ore mineral slurry pipelines have been built: the world's first loading of Iron Ore slurry without a deep water terminal commenced in 1971at Waipipi, N.Z., the 18 km N.Z. Steel iron sand pipeline was commissioned in 1986, and most recently the 62 km OneSteel Whyalla magnetite pipeline commissioned in 2007. A number of iron ore slurry pipelines were built in Brazil and India, transporting both magnetite and hematite. A number of slurry pipelines are under consideration for mine development in Western Australia.

The current paper reviews the development of long distance iron ore pipeline technology, describes the existing pipelines in the Australian region and considers the engineering, construction, operation and current status and future of long distance iron ore slurry pipelines in Australia.

1.0 INTRODUCTION

The long distance transport of iron ore slurry by pipeline is a commercially proven technology with a 44 year history. Slurry pipeline technology has advanced to the point where technical feasibility and hydraulic design of a new system can be established by laboratory testing of a 20 litre representative sample of the slurry to be transported. A slurry pipeline option is a consideration in studying of alternative modes of transportation for development of mineral, iron ore or coal projects.

Long distance transportation of solids by slurry pipeline is an evolving technology which commenced in 1957 with the 172 km Ohio coal pipeline in USA. Prior to 1957 most slurry pipelines were short distance dredge and mine tailings pumping systems. With Ohio coal pipeline, Ed Wasp of USA pioneered the application of fully welded and buried oil and gas pipeline technology to coal and mineral slurry transport.

In the iron ore industry, particularly with low grade ores requiring processing to extract the ~~magnetite~~ concentrate to create a high grade iron ore pellet for steel manufacture, a slurry pipeline is suited to transport the ~~magnetite~~ concentrate produced in a mine site preparation plant and dewatering facility located adjacent to existing transport facilities or port site for pelletising or direct shipment. Slurry pipelines are used to transport both fine magnetite and hematite.

2.0 THE SAVAGE RIVER IRON ORE PIPELINE IN TASMANIA A WORLD'S FIRST

2.1 Why a Slurry Pipeline?

Pickands Mater & Co, USA, recognised early in the evaluation of the Savage River property that transportation of the material from the remote area to the coast was a fundamental factor in making Savage River a feasible project.

The Bechtel Corporation was selected to engineer and construct the slurry pipeline once the development and preliminary engineering work was completed. The handling of magnetite slurries was not new to Pickands Mater & Co. Pumping of similar materials at Erie Mining Company in Minnesota had be carried out over the past 10 years. Approximately 70,000,000 tons of slurry at 50 to 55% solids had been pumped over a multiple line installation of approximately 500 m~~1500 feet~~.

2.2 Project Development

The technical development for the design of the Savage River slurry pipeline extended over three years and involved initial laboratory tests of concentrate samples to determine the base slurry properties, followed by correlation with known data from the commercially proven Ohio coal slurry pipeline. The analysis encouraged further development, which involved more correlation with data from loop testing of similar iron ore slurries at the Colorado School of Mines. These studies centred on limitations of pipe loop testing in comparison with the experience through the Consolidation pipeline as well as limitations on pipeline slope, transportation of top size particles and pipeline shutdown and restart with slurry in the pipeline.

A key element in the evolution of long distance slurry pipelines is the adaptation of cross country oil and gas pipeline technology to transport of minerals and coal in slurry form. Cross country oil and gas pipelines are fully welded, low carbon, high strength steel pipes, externally coated and buried. The buried pipeline is further protected from external corrosion by an induced current cathodic protection system. Oil and gas pipelines are laid cross country in a fairly direct line between terminals. The pipeline is buried at a depth to allow the land to revert to its prior use.

Unlike long distance water supply pipelines, cross country slurry pipelines have no requirement for either air valves at high points or drain valves at low points. However, development tests for the Savage River pipeline determined the need to restrict the maximum slope of the pipeline. On shutdown the slurry in the pipeline settles homogeneously to form a two layer area, a high density bed in the lower half of the pipe with a clear water layer in the top half of the pipe. In theory, restricting the slope of the pipe prevented migration of the higher density layer down slope to form a high density plug of slurry in the low points of the pipeline. In practice some migration of the settling slurry to low points does occur, however, provided the higher density slurry accumulated in the low points remains reasonably fluid the pipeline can be restarted to resuspend the slurry. Some density gradients in the slurry occur, but the average pressure drops are within design specification. For Savage River, the maximum slope was restricted to ±10%. More recent experience indicates slopes up to 16% are satisfactory.

The technical program included development and testing of a high pressure positive displacement pump suited for continuous operation, pumping highly abrasive magnetite concentrate at pressures in excess of 2,000 psi (13.8 MPa). The program involved upgrading the existing drilling mud pumps used in the oil drilling industry to suit 365/24 operation in the mining industry. Major innovation included adopting a flush plunger configuration in lieu of the conventional piston pump in the drilling industry. In addition, the pump drive was beefed up for continuous service.

The Savage River iron ore slurry pipeline commenced transporting magnetite concentrate on October 26, 1967 and has operated continuously for over 43 years.

The Savage River pipeline was required to transport 2,250,000 tonnes of magnetite per year An optimum pumping concentration of 60% solids by weight and an operating velocity of 1.68 m/s were predicted with the requirement for a non-standard pipe diameter of 9 inches (that is 9.625 ins. – 244.5mm) OD steel pipe. The pipe, sourced from Japanese steel mills, was manufactured to American Petroleum Industry Specification (API) 5L Grade X52 with a pipe yield stress of 52,000 psi (358.5 kPa). The ground profile and hydraulic gradient is shown in Figure 2.1

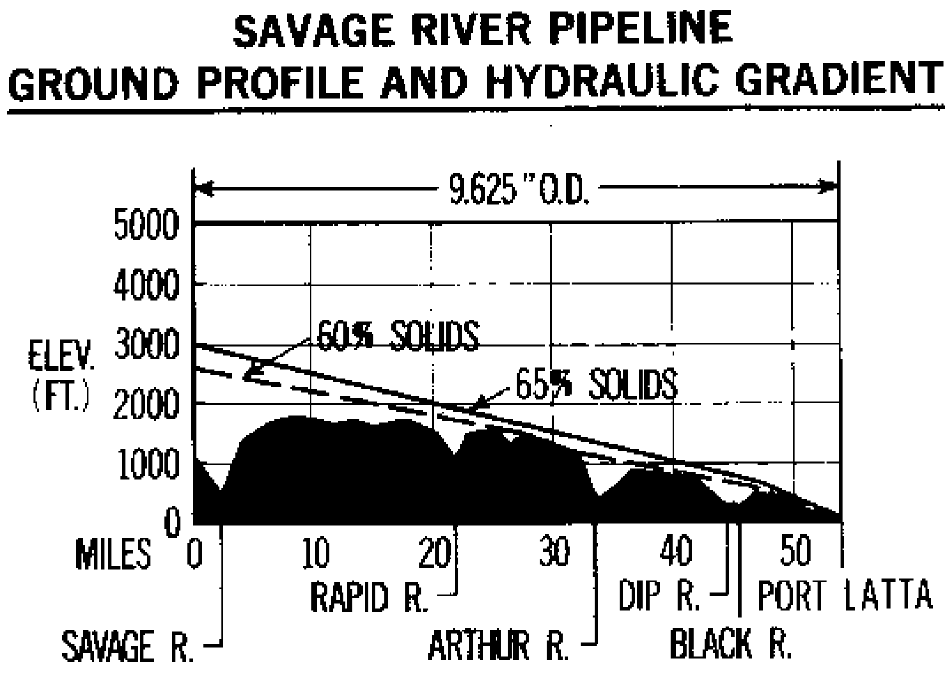

Figure 2.1 Savage River Pipeline Ground Profile and Hydraulic Gradient

Long distance slurry pipelines operate at high pressure. The Savage River pipeline has a discharge pressure of 11.5 MPa and requires positive displacement pumps to create sufficient pressure to maintain pipeline hydraulics.

3.0 IRON ORE SHIPLOADING BY PIPELINE – OIL TANKER FASHION

3.1 Wai~~ia~~pipi Slurry Shiploading

The World's first pipeline loading of bulk mineral commodities aboard a tanker offshore, without a deep water port was successfully completed on July 5, 1971, at Waipipi, New Zealand. The Waipipi shiploading system was based on single point oil tanker loading systems developed for the oil industry. The Waipipi cargo consisted of 43,000 tonnes of ironsands concentrate in slurry form. The ironsands were pumped offshore via a 2.4 km, DN300 submarine pipeline to the ore carrier which was moored to a single point buoy more than 2.4 km off the rugged west coast of New Zealand's North Island. The facilities diagram is illustrated in Figure 3.1~~2.2~~.

The shiploading system was designed to load ironsands at 1,012 t/hr in a slurry of 45% solids by weight. The maximum particle size is 589 microns with a particle solids specific gravity (SG) of 4.9.

A total of six 14" x 16" high pressure centrifugal pumps (case pressure 4,600 kPa) were installed in series to provide the loading hydraulics. Each pump was driven by a 600 kW, 4-pole electric motor. The first three pumps were fixed speed driven via a reduction gearbox. The remaining three pumps used variable speed couplings.

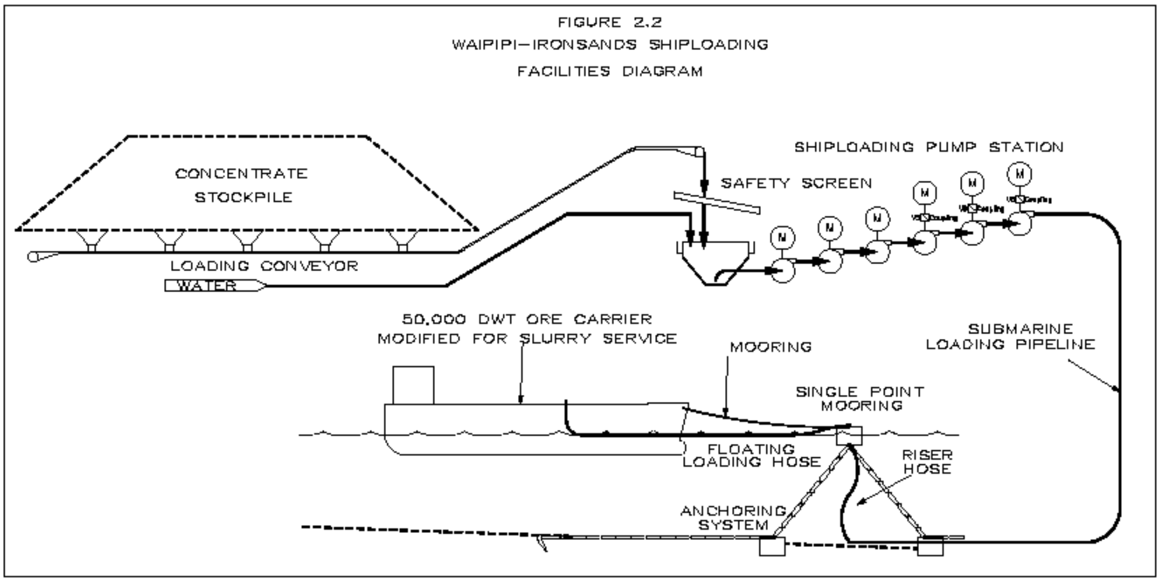

Figure 3.1~~2.2~~ Waipipi Ironsands – Shiploading Facilities Diagram

3.2 Slurry Shiploading – Future Application to the Iron Ore Industry

The success of the Wai~~ia~~pipi Iron Sands Systems can be applied to loading of magnetite concentrates in future project developments. The advantage of the system is loading of the ship by submarine slurry pipeline and single point mooring does not require a conventional port. The ore tanker moors to a single point mooring located offshore and the magnetite slurry is pumped onboard. The magnetite settles in the ships hold and the excess water can be recycled to the shore loading facilities or discharged to the sea. The system is fully automated requiring minimal operating staff. There is a need for a crew to assist in mooring operation. However, there is no need for a tug.

The slurry ship holds requires static screens and screen underflow pumps to minimise the amount of moisture in the cargo at the end of loading. Historically, moisture contents of 12 to 14% have been achieved by the end of loading.

The cargo can be discharged at the receiving end of the voyage by conventional grab unloading facilities. However, it is feasible to engineer a system that incorporates both loading and unloading in slurry form.

4.0 LONG DISTANCE IRONSANDS PUMPING – NZ

The success of the Waipipi system over a period of 12 years assisted in the development of a unique technical step in slurry technology resulting in NZ Steel's long distance ironsands pipeline from Taharoa to Woolf Fisher Steel Mill in South Auckland, a distance of 18 km. The NZ Steel pipeline was an extension of experience from both Savage River and Waipipi ironsands technologies. The significant technical developments were the application of long distance oil and gas, cross country pipeline technology to transport coarse ironsands concentrate. The NZ Steel pipeline required a wear resistant liner and the Waipipi experience determined wear in rubber lined pipe was minimal. Spun cast polyurethane was selected as the preferred liner for the NZ Steel pipeline. However, the key technical question was how to join the polyurethane lined pipes by a welded joint to allow long distance pipeline construction methodology. As a consequence, a unique, high pressure welded coupling was developed to allow down-hand welding without destroying the bond between the polyurethane and steel pipe. A section of the welded coupling is shown in Figure 4.1~~2.3~~.

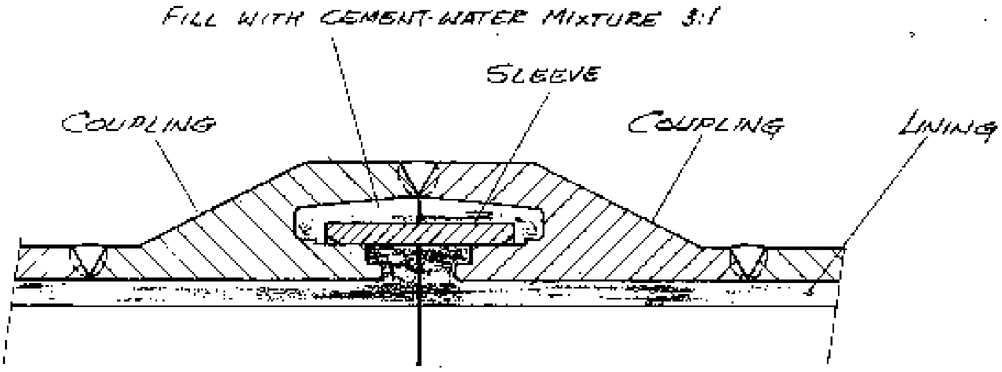

Figure 4.1~~2.3~~ Typical Special Welded Coupling

The basic principle of the coupling was to control the temperature rise at the polyurethane/steel bond during the down-hand joint welding operation.

The NZ Steel pipeline system incorporates two pump stations, each with a discharge pressure of 9.9 MPa. In 1990, the NZ pipeline system was recognised as a world's first with a unique contribution (one of only seventy awards) to the engineering history in New Zealand.

5.0 RECENT IRON ORE PIPELINES – ONESTEEL WHYALLA

OneSteel Limited operate a steel making plant at Whyalla, South Australia. The plant has operated for many years using hematite ore from nearby deposits. The start-up of mining of an associated magnetite deposit can supply the steel plant for another 25 years. The magnetite is transported from the mine to the steel plant via a new slurry pipeline. The pipeline was commissioned in August 2007.

5.1 Magnetite Slurry Pipelines

The slurry pipeline pump station is located adjacent to the concentrator at the minesite. The magnetite slurry is received from the thickener into two relatively small 10 m diameter x 10 m high agitated slurry storage tanks at the pump station. Each agitator is driven by a 45 kW motor. Two variable speed centrifugal charge pumps, one duty and one standby, receive slurry from the agitated storage tanks and deliver the slurry at a controlled pressure to the mainline piston diaphragm pump. The mainline pump is a Geho triplex piston diaphragm pump rated at 222

m^3/h driven by a 1050 kW variable speed motor and maximum discharge pressure is 15.3 MPa. Normal flow rate is 205 m^3/h representing 48 strokes per minute.

The slurry in the agitated storage tanks is received at a nominal concentration of 70%. The concentration of the slurry is adjusted by controlled dilution prior to the charge pumps. The pumping concentration varies between 55% and 65% depending on production and slurry properties. The nominal production is 250 tph of magnetite. The pump station includes lime and chemical injection facilities to control internal corrosion of the unlined pipeline. The pipeline operating procedures include regular monitoring for internal corrosion.

The 62km DN200 slurry pipeline is installed buried adjacent to the DN400 return water pipeline. Fibre optic cables are also installed in the common trench. The pipelines are laid at a nominal depth of 750 mm however burial depth varies up to 1200mm for protection reasons based on detailed consideration of the land use of each area that the pipeline crosses. The pipeline is externally coated with anti corrosion coating. The internal surface of the pipeline is bare steel. A variable corrosion allowance has been used along the pipeline. The design hydraulic gradient is shown in figure 5.1. The pipeline wall thickness is telescoped in order to reduce pipe steel requirements from 8.2mm to 4.8mm generally reducing towards the low pressure end. However thicker wall thickness pipe is installed in some locations for protection reasons.

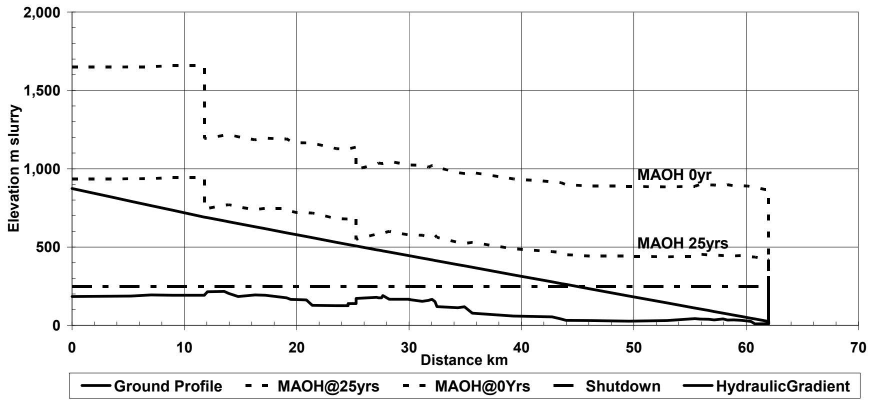

Figure 5.1 DN200 Slurry Pipeline Hydraulic Gradient

No air release valves are installed on either the slurry or return water pipelines and the pipelines follow the ground undulations with no special grading of the pipelines. No mainline isolation valves are installed along the length of the pipeline. A pig launcher and receiver are included at the start and end of the pipeline respectively. The control system sequences valve operations to prevent over-pressurisation and emergency pressure relief systems are also installed.

The pipeline is automatically controlled under the supervision of the concentrator operators. The operator selects the concentration of the slurry to be transported. Flushing, batch and stop - start operations are supported. Automatic leak detection is programmed based on monitoring the input from flowmeters installed at the start and end of the pipeline.

5.2 Return Water Pipeline

The return water pipeline pump station is located adjacent to the pellet plant at Whyalla. Two sets of two centrifugal water pumps are installed, one set standby and one duty. The return water pumps are driven by 500 kW motors. Early in the project consideration of the economics and technical aspects of various operating options indicated that fixed speed pumps with flowrate determined by control valves was the most cost effective alternative. The pump station includes lime and chemical injection facilities to control internal corrosion of the unlined pipeline. The operating procedures include monitoring for internal corrosion. The flow rate of the pipeline can vary from 371 to 560 m^3/h. The maximum inlet pressure is 4000 kPa.

The 62km DN400 return water pipeline is installed buried adjacent to the DN200 slurry pipeline. The pipeline is externally coated with anti corrosion coating. The internal surface of the pipeline is bare with a uniform corrosion allowance applied. The design hydraulic gradient is shown in figure 5.2. Generally a constant wall thickness of 6.4mm is used for the return water pipeline, however thicker wall pipe of 9.5mm is specified for some locations based on the consideration of protection requirements.

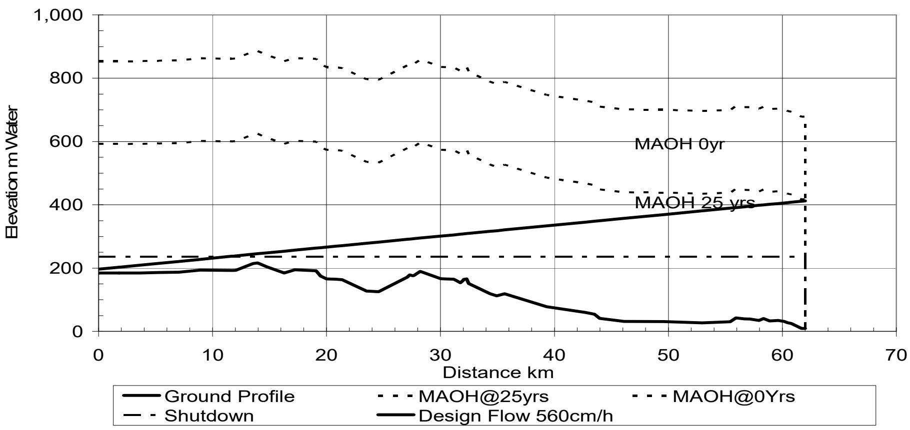

Figure 5.2 DN400 Return Water Pipeline Hydraulic Gradient

A pig launcher and receiver is included at the start and end of the pipeline respectively. There are no intermediate mainline isolation valves, scour valves or air release valves installed along the pipeline. For start up purposes pigs were run to clear the pipeline of any air. Air was also released during start-up from manual valves located at two high points at the crossover connections to the slurry pipeline.

The flowrate from the fixed speed pumps is automatically controlled by the control valve to the set point selected by the operator. Automatic control is also possible in response to varying tank levels. Quick acting surge relief valves are installed at the start and end of the pipeline. Automatic leak detection is programmed based on monitoring the input from magnetic flowmeters at inlet and outlet.

6.0 ENVIRONMENTAL ISSUES

The design and construction of cross country slurry pipelines is soundly based on standards developed for oil and gas pipelines. However, the slurry pipeline has the added advantage of being inert and non-explosive.

In comparison with the alternative transportation modes, slurry pipelines have minimal impact on the land traversed. The slurry pipeline is buried with a standard cover of 750mm, which allows the land traversed to be used for agricultural or pastoral activities.

7.0 OTHER TECHNICAL FACTORS FOR IRON SLURRY PIPELINES

7.1 General

There are a number of technical factors determining the application of slurry pipeline technology to transport iron ore.

7.2 Particle Size Consist

The particle size consist suited to long distance pumping of an iron ore by slurry pipeline must generally be finer than 1 to 2% minus 105 microns. Coarse ROM ore is not economically pumpable.

7.3 Lined or Unlined Steel Pipes

The selection of lined or unlined bare steel pipe is an issued generally addressed early in the feasibility phase of a pipeline project. The decision is both technical and economic. The Savage River and OneSteel pipelines are both unlined, bare steel.

Laboratory corrosion tests of representative iron ore slurry to be pumped are used to determine the pipe metal loss due to corrosion. In general, a freshly created slurry is devoid of dissolved oxygen and a bare steel pipeline will give long term service by controlling the pipe corrosion by raising the slurry pH with the addition of lime to a pH in the range of 9.5 to 10.5. The corrosion rate allowance is generally in the order of 0.1 mm of steel per year, with 2.5mm for, say a 25 year life system.

The alternative to unlined pipe is to install an inserted High Density Polyethylene (HDPE) liner. The HDPE liner thickness varies with steel pipe diameter with HDPE liner inserted in about 1km steel sections. The steel casing is designed for the internal operating pressure and the inserted HDPE liner offers corrosion protection.

Both bare steel and HDPE inserted lined options can be assessed on Whole of Life costing and may vary for individual cases.

7.4 Reliability

Long distance slurry pipelines have a high reliability with proven availability in the range of 95 to 99%. The high availability is achieved by installing one standby mainline pump for maintenance purposes.

7.5 Automation

Slurry pipeline operation is highly automated not requiring a dedicated operator. The pipeline system is generally remotely operated by the concentrator operator as part of his normal duties via the central DCS system.