SLURRY PIPELINES – PAST, PRESENT AND FUTURE

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ABSTRACT

The world's first long distance 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 slurry pipelines have been built: the 24 km Gladstone limestone pipeline, the 18 km N.Z. Steel iron sand pipeline, the 304 km Century zinc/lead concentrate pipeline and most recently the 62 km OneSteel Whyalla magnetite pipeline commissioned in 2007.

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

Keywords: coal pipeline, slurry pipeline

1 INTRODUCTION

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. The world's first long distance mineral slurry pipeline was built in 1967 for the Savage River magnetite concentrate mine in Tasmania. Since then, in the Australasian region, a number of slurry pipelines have been built transporting copper, lead, and zinc concentrates as well as magnetite, limestone, and ironsands. There is currently considerable interest in slurry pipelines for a number of potential projects.

2 PAST - HISTORICAL EVOLUTION

2.1 The 174 km Ohio Coal Pipeline - The World's First Long Distance Slurry Pipeline

Mr E.J. Wasp, formerly of Bechtel Corporation USA, is considered the father of "long distance slurry pipeline technology". Ed Wasp applied oil and gas technology to develop the 108 mile (174 km), 10 inch (DN250) coal slurry pipeline for Consolidation Coal in Ohio, USA. Ed Wasp's experience at Consolidation Coal culminated in the development of a comprehensive mathematical model to predict slurry hydraulics from laboratory test data. The model inputted solids specific gravity; % solids in slurry; particle shape factor; slurry rheology and fluid properties to correlate the actual pipeline hydraulics as experienced in the Ohio pipeline.

2.2 The Savage River Iron Ore Pipeline in Tasmania – A World's First

The Savage River iron ore slurry pipeline commenced transporting magnetite concentrate on October 26, 1967 and has continuously operated for over 41 years. The technical development for the design of the 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 it's 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 occurs, 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 Savage River pipeline was required to transport 2,250,000 tns of magnetite per year An optimum pumping concentration of 60% solids by wt. 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

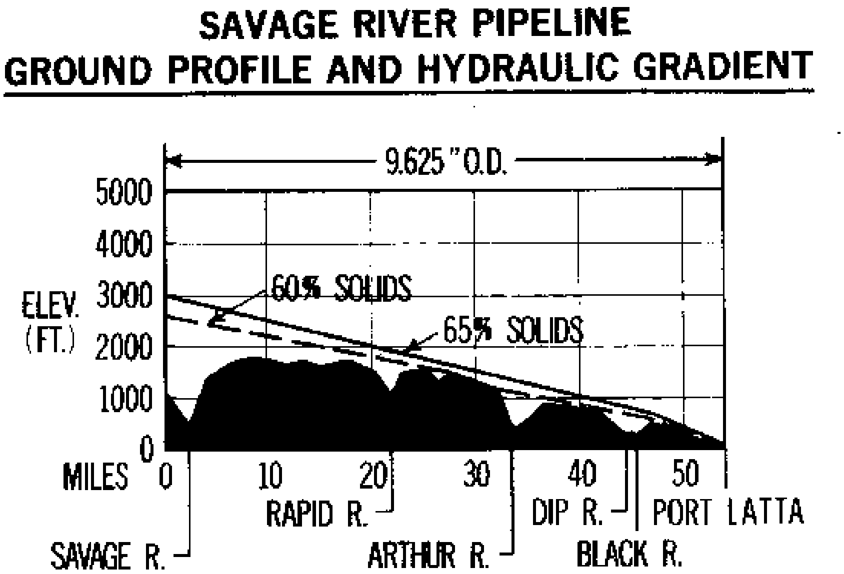

Figure 2.1 Savage River Pipeline Ground Profile and Hydraulic Gradient

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. At the time Savage River was engineered, it was necessary to select a positive displacement pump from a similar service. The pump selected was again sourced from the petroleum industry. The selected pump was a Wilson Snyder, flush plunger pump conventionally used for pumping drilling mud. The Wilson Snyder drilling mud pump was mechanically upgraded, primarily by upgrading the bearings for the continuous 365 day, 24 hr per day service.

2.3 Copper Concentrate Slurry Pipelines in PNG

The success of the Savage River Pipeline ushered in the adoption of slurry pipelines to transport copper concentrate in mine developments of the late 1960's early 1970 mining boom. Copper concentrate slurry pipelines were an advantage to the developments of mineral deposits in the jungles of Papua New Guinea. The copper minerals were extracted at the remote mine site and the resulting concentrate was transported to the coast by slurry pipeline. At the coast the slurry was filtered to create a concentrate filter cake prior to shipment. In most cases the mine was in the mountains and the terminal was near sea level on the coast. Hence, gravity assisted the pipeline hydraulics.

The two earliest systems were the Bougainville Copper Concentrate Pipeline (27 km DN150) and the Irian Jaya Ertsberg Project (111 km DN100) both in 1972 followed by the Ok Tedi pipeline (156 km DN150) in 1986. The pipeline hydraulics for engineering these pipelines were computer predicted based on proprietary mathematical models. Laboratory data measured from testing of 20 litre representative samples of the concentrate to be pumped was inputted to the model to predict minimum operating velocity and pipeline friction loss. The prediction of slurry hydraulics based on laboratory testing was a significant technical breakthrough. The procedure eliminated the need for pipe loop tests which required 30 tns or more of concentrate. The production of 30 tns of copper concentrate would require in excess of 1500 tn ore sample - a significant cost in the early phases of project development.

Each project required the building of an access road through the jungle for transport of equipment, materials and personnel for mine development and operation. The slurry pipeline was buried in the access road shoulder.

The access road provided a platform for pipeline construction equipment. The Erstberg project was, by far, the most inaccessible mine. The elevation varied from sea level at the port site to about 3,350 m at the mine site. The concentrator and slurry pump station were at 2,750m. The maximum slopes in the escarpment are up to 28%. Transporting major equipment up the escarpment was achieved by dragging the transports with a D9 bulldozer.

However, after 1 years operation the Irian Jaya pipeline experienced major leaks in a region where the hydraulic gradient line intersected the ground profile resulting in slack or open channel flow. After the Irian Jaya experience, all long distance slurry pipelines eliminated slack flow by installing choke stations to hold back the pressure to maintain a packed line.

2.4 Slurry Shiploading – Ironsands Pumping

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 tns of ironsands concentrate in slurry form. The ironsands were pumped offshore via a 2.4km, DN300 submarine pipeline to the ore carrier which was moored to a single point buoy more than 2.4km off the rugged west coast of New Zealand's North Island. The facilities diagram is illustrated in Figure 2.2

The shiploading system was designed to load ironsands at 1,012 tn/hr in a slurry of 45% solids by wt. The maximum particle size is 589 microns with a particle solids 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.

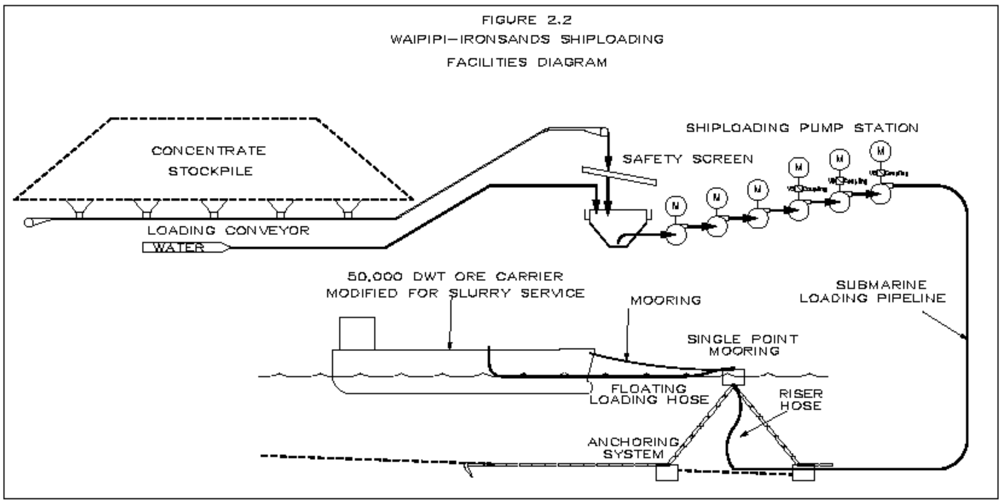

Figure 2.2 Waipipi Ironsands – Shiploading Facilities Diagram

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 18km. 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 2.3.

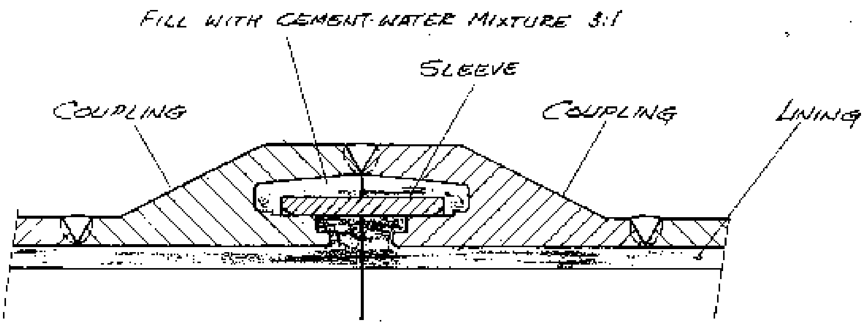

Figure 2.3 Typical Special Welded Coupling

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.

2.5 Long Distance Pipeline – Cement Industry

The manufacture of Portland Cement up to fairly recent times was a wet process. Quarried limestone was ground in slurry form to form a high density slurry to which clay, sand and ironstone was added to form a kiln feed slurry. In more recent times, the wet process has been replaced by a dry process to save energy lost in the drying of the kiln slurry. A long distance slurry pipeline was an ideal method to transport the limestone slurries for the wet process. The slurry pipeline allowed the cement manufacturing to be undertaken on a separate site to the limestone quarry. In 1981 the Queensland Cement and Lime Company Ltd, commissioned the 24.2km long DN200 steel pipeline from an inland limestone quarry to a new cement manufacturing plant near Gladstone, Queensland.

3 PRESENT - EXISTING SLURRY PIPELINES

3.1 Century Zinc/Lead Concentrate Pipeline

The 304 km DN300 Century pipeline transports zinc and lead concentrates from the Century mine in NW Queensland to Karumba on the Gulf of Carpentaria. At Karumba the concentrate is filtered then loaded onto a barge for subsequent loading onto a ship moored offshore in the Gulf. The pipeline was commissioned in 1999 and was the first slurry pipeline in Australia to incorporate a High Density Poly-Ethylene (HDPE) liner. All the early pipelines described in Section 2 (except the polyurethane lined NZ Steel pipeline) were unlined, bare steel pipelines. Internal corrosion was controlled by raising the pH to around 10 by addition of lime. The extraction process for Century zinc concentrate involves extremely fine grinding such that 80% of the particles are finer than 7.5 microns. The froth flotation process results in up to 20% air in the form of micro-bubbles attached to the fine particles. This air is tenacious and there is no easy way of removing it from the slurry prior to pumping. The presence of the air could be conducive to corrosion and for this reason the HDPE lining option was selected.

The pipeline is welded in lengths of up to 2 km with bolted flange joints joining each length. During construction the steel and HDPE pipes are welded into the 2 km length. The HDPE pipe is then pulled through the steel pipe by a special process involving reducing the OD of the HDPE pipe by passing it through a set of rollers prior to entering the steel pipe through which it is pulled using a steel wire. The length between flanged joints depends on the number and severity of bends in the length.

The Century pipeline was the first slurry pipeline in the world to transport two different products in the one pipeline. The zinc and lead concentrates are transported in batches with approximately one hour water slug separation. The Century pipeline is also the longest slurry pipeline in the world with a single pump station. Three Wirth TPM 83/4x14 piston diaphragm pumps each driven by a 1130 kW electric motor are installed in parallel with generally two operating and one on standby. Design pump discharge pressure is 18,000 kPa with typical operating pressure around 12,000 kPa.

As is the case with all slurry pipelines today, the Century pipeline was designed entirely from bench scale laboratory tests. No pipe loop tests were conducted prior to pipeline construction. The test work included rheology tests, settling tests and solids SG determination. From the laboratory test data the pipeline hydraulics were determined and pipe size and pump requirements specified.

3.2 OneSteel Whyalla Magnetite Pipeline

The 62 km DN200 OneSteel magnetite pipeline transports magnetite concentrate from the Iron Duke mine to Whyalla, S.A. and was commissioned in 2007. The pipeline is unlined steel with corrosion control by lime addition to maintain high pH. The Whyalla pipeline is the first slurry pipeline in the world to incorporate a return water pipeline. A DN400 parallel water pipeline returns the water from the slurry pipeline plus additional water required for mine use.

Hitherto all slurry pipelines have required a water supply at the mine site. However environmental concerns and water shortages will probably mean that most new slurry pipelines in Australia will require a return water pipeline.

4. FUTURE – POTENTIAL NEW SLURRY PIPELINES

4.1 Coal Slurry Pipeline Technology

The transportation of coal by long distance slurry pipeline is a proven technology that has been studied in Australia. However, to date, no long distance coal pipelines have been installed in Australia. Conventional coal transportation by slurry pipeline requires the coal to be crushed to create a slurry to a specification suited for pumping. The coal size is limited to a particle top size of 1.5mm. In addition, the coal slurry preparation circuit uses cage mills to ensure a normal size distribution with a minimum of 20% passing 45 micron. The slurry is prepared as a 47 to 50% by weight slurry. The weight % will vary depending on the inherent moisture content of the coal. Lower grade coals require more water. The conventional coal slurry pipeline is especially suited to transport coal to a captive power station, since coal is ground finer in the power station pulverisers prior to burning.

The Black Mesa coal slurry pipeline, commissioned in 1970, is the prime example of coal slurry technology. The Black Mesa pipeline is 273 miles (439 km) long and the majority of the length is composed of 18 inch bare steel pipe (DN450). The Black Mesa pipeline receives coal from the Black Mesa Mine adjacent to Keyenta Arizona and delivers it to the Mohave Power Station located on the Colorado River, south of Las Vegas, Utah. The Black Mesa system has a total of 4 pump stations, 3 pump stations have 3 pumps in parallel whilst the fourth station has 4 pumps in parallel. The pump drives range form 1,120 to 1,300 kW.

Power stations in Australia are normally installed close to the coal mines with the resulting electricity transferred to the load centres by high voltage power lines. Locating the power station on the coast for cooling by seawater and transporting the coal from the mine by buried slurry pipeline offers a more economical solution. Refer to a technical paper by K Dawson and M Sargant of the State Electricity Commission of Queensland, titled “Energy Transportation – A Case Study for the Electricity Supply Industry, 1976”.

4.2 Coarse Coal Slurry Transport – SVS System

Since the fine coal product from a conventional coal slurry pipeline was not suited to the current export steaming coal market, Slurry Systems extended the fine coal slurry pipeline technology to transport coarse product coal of 30mm x 0 size in a special vehicle slurry (SVS) system. The SVS system transports the coarse product coal in a recycled vehicle slurry. The vehicle slurry is composed of fine coal and magnetite with a slurry specific gravity similar to the coarse coal particle specific gravity. The facilities in a coarse coal – SVS pipeline system are illustrated in Figure 4.1.

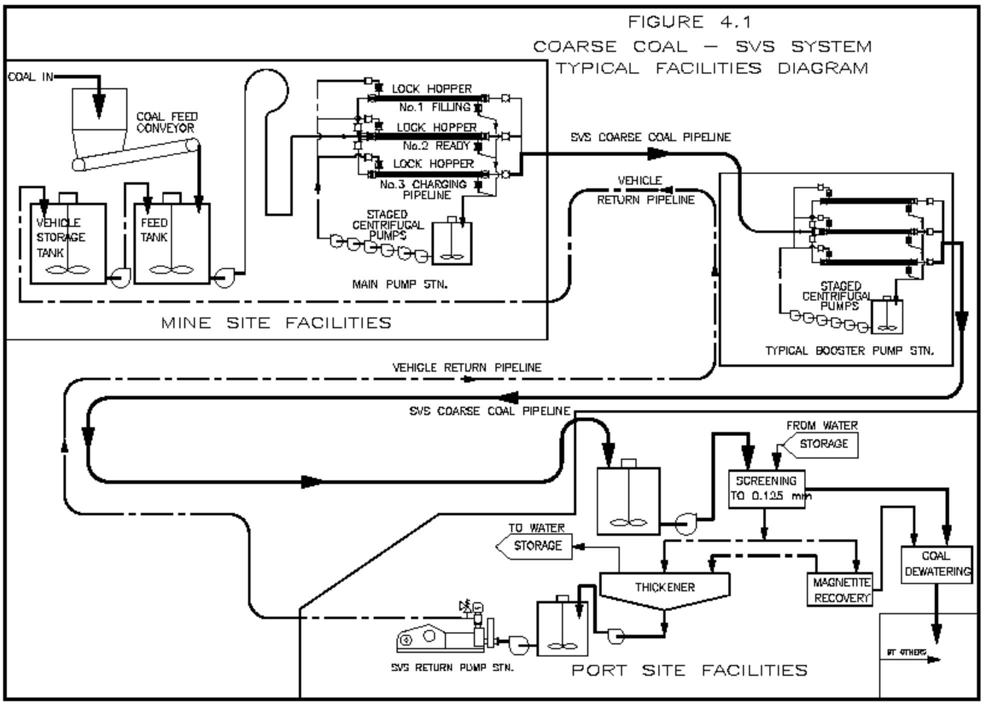

Figure 4.1 Coarse Coal – SVS System Typical Facilities Diagram

4.3 Potential Slurry pipelines

Examples of some of the potential future slurry pipelines recently considered in the Australian region are shown in Table 4.1

TABLE 4.1 Potential Slurry Pipelines in the Australian Region

Transported Material	Thoughput Million tonnes per annum	Length km
Magnetite	15	70
Magnetite	10	110
Magnetite	10	240
Magnetite	7	400
Magnetite	6	90
Nickel	4	180
Coarse Coal (SVS)	10	280
Copper	0.5	100
Copper	0.5	180

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Many of the potential pipelines are for the transport of magnetite concentrate with a trend to larger throughputs when compared to the existing Savage River and Whyalla magnetite pipelines. Most of the potential pipelines consider a parallel return water pipeline system except for the smaller copper pipelines.