The
Institution of Engineers,
Australia

Slurry Handling and Transportation Developments

G.R. RIGBY
and
A.D. THOMAS

Australian Coal Miner March 1984, p16.

International Conference on Bulk Materials Storage, Handling and Transportation, 1983, Newcastle, 22-24 August

Slurry Handling and Transportation Developments

G.R. RIGBY
BHP Central Research Laboratories, Shortland, NSW
and
A.D. THOMAS
Consultant, Newcastle

SUMMARY The expanding role of slurries in providing means for the utilisation, handling and transportation of a wide range of bulk solids will continue to be an important factor in the future development of our mineral resources. Recent developments in slurry technology with particular reference to conventional long distance transportation, coarse solids pumping and energy slurries are reviewed.

1 INTRODUCTION

A large proportion of all bulk materials are currently being handled and transported throughout the world in the form of slurries. New developments in slurry technology offer the potential to increase the range of these materials and applications. Typical examples of present and potential applications include the following:

- long distance transportation of coal and other minerals
- slurries for utilisation in combustion and energy conversion applications, for example coal-oil-mixtures, coal-water slurries, coal-methanol slurries etc.
- relatively short distance conveying and in-plant slurries, for example hydraulic hoisting of coal, in-plant transportation such as in coal washeries and beneficiation operations
- utilisation of slurry system for loading and unloading ships
- tailings and fly ash disposal systems
- sand mining and beneficiation operations
- chemical reactor and processing slurries, for example alumina processing, hydroliquefaction of coal
- concrete pumping applications
- sewerage and other waste disposal systems.

The size range of materials handled in slurries can vary from 100 to 150 mm down to a few microns. An understanding of the properties of the various slurries and their effects on operating parameters is essential in ensuring the reliability of the system. This paper reviews some of these features with particular reference to recent developments in the areas of transportation and energy conversion applications.

2 LONG DISTANCE TRANSPORTATION

One of the attractions of oil and gas is the ease with which they can be transported over long distances by pipeline, a clean and economically attractive transport medium. By comparison, the traditional means of transporting many bulk solids by rail, truck and conveyor is cumbersome.

The transportation of these materials by pipeline is now feasible and such operations have now become a standard part of the overall system for moving bulk materials in many parts of the world (Rigby, 1982).

Typical examples include the following:

(i) the Black Mesa pipeline which has been conveying 5 million tonnes per year of coal over a distance of 439 km from a mine in Arizona to the 1500 MW Mohave power station in Nevada since 1970 (Montfort 1982)

(ii) the 396 km Samarco iron ore pipeline in Brazil which has a capacity to transport 12 million tonnes per year of hematite concentrate from a beneficiation plant 300 km north of Rio de Janeiro to a pellet plant at Point Ubu (Stetler, 1982)

(iii) the 24 km Gladstone limestone pipeline in Queensland which was commissioned in 1982 and transports a limestone-clay slurry from a new quarry and grinding plant at East End to a new cement clinker plant at Fishermans Landing (Venton, 1982).

One of the areas where significant advancement and expansion in slurry pipeline technology and operations is likely to occur is in the movement of coal. The Black Mesa operation, having transported some 50 million tonnes of coal, has demonstrated the technical and economic viability of this mode of transportation.

In the U.S.A. additional pipelines to convey in excess of 100 million tonnes per year of coal over a total distance in excess of 10,000 km have been proposed (Rigby, 1982). The most advanced of these is the 2300 km long ETSI pipeline from Northern Wyoming to various energy utilities in Arkansas, Louisiana and Mississippi (Wasp, 1982). This pipeline will have an internal diameter of the order of 1 m and an annual capacity of approximately 30 million tonnes. Whilst this system will use a similar pipeline slurry to that used in the Black Mesa operation, the ETSI organisation has introduced some novel additions to the dewatering circuit to yield a product having a surface moisture between 7 and 11% (compared to the Black Mesa product surface moisture of approximately 16%). The lower level of product moisture is achieved using a combination of screen bowl centrifuges and vibrating bed dryers. It has been claimed that this product can be handled with conventional equipment and stockpiled successfully under adverse climatic conditions (Derammalaere et al. 1982).

Like the Black Mesa system the ETSI pipeline will use a fine coal slurry (coal top size approximately 1 mm) to give optimum pumping characteristics and pressure gradients.

This technology is basically limited to energy coal being supplied to local power generation stations or other pulverised fuel users. The product is not generally suitable for the export market or for coking coal applications, primarily due to the size of the coal (Rigby and Callcott, 1972).

In Australia, a joint venture between the Broken Hill Proprietary Company Ltd. (BHP) and British Petroleum Australia (BPA) is developing an alternative fine coal transportation/beneficiation system (Elkes et al. 1982). This development (IPTACCS - Integrated Pipeline Transportation and Coal Cleaning System) uses oil agglomeration techniques to allow the fine coal to be recovered from the slurry in the form of agglomerates which are potentially suitable for local or export use as either energy or coking coals. A 30 tonne/hour demonstration plant, near Newcastle is being operated to develop this technology on a commercial basis (Rigby et al, 1982). The demonstration plant has facilities for recovery and recycle of the oil to the process to yield a product containing less than 0.5% (by weight of coal) residual oil. In some applications, for example in the preparation of coal-oil mixtures or in hydroliquefaction operations it is not necessary to recover the oil. As well as providing a means of transport, the process provides for beneficiation of the coal, thus avoiding the necessity of a conventional washing plant. Other potential advantages include improved yields of coal compared to conventional systems and lower product moistures (6 to 10% for product containing oil or 2% for de-oiled product).

The IPTACCS process is also being developed in conjunction with the Electricity Commission of New South Wales for the combined beneficiation, transportation and production of dry pulverised coal for direct firing in a power station boiler. A 30 tonne per hour plant is currently being commissioned to test the process on a 60 MW boiler (Rigby et al. 1983).

The economics of these fine coal systems compared to conventional transportation systems (e.g. road, rail, conveyor) are dependent on the particular case. However many studies have shown that for a new system, the capital costs of a slurry pipeline system can be of the order of 50% of that for the alternative systems. Operating costs for the pipeline operation are also generally lower, particularly when the lower costs associated with inflation effects are taken into account (Rigby et al., 1983 , Kennett, 1981, Rigby, 1982, Pike, 1982, Dawson and Sargent, 1975, Dawson et al., 1980).

3 DEVELOPMENTS IN COARSE SOLIDS PUMPING

Optimum pumping properties for slurries are achieved when the particle size is small. Typically median particle sizes ranging from about 150 μm for coal to 30 μm for iron ore are necessary. Such materials have a wide particle size distribution with top sizes about an order of magnitude higher, i.e. 1.5 mm and 0.3 mm respectively. For these slurries the pressure gradient is low and pipe wear is almost negligible. However there are numerous cases when it is either not economic to reduce the particle size or when the end product is required to be large. Typical examples are tailings disposal from mineral processing plants, pumping material in chemical and mineral processes, sand mining, coarse coal transportation, dredging and concrete pumping. The two main problems caused by the coarser particle size are high pressure gradients, often 5 to 10 times that of a fine particle slurry, and high pipe wear rates. Current developments aim to minimise these two problems.

The centrifugal pump is the most common pump for these slurries and pump developments include better wear resistant pumps and the extension of pump casing pressure limits to permit higher pump station pressures by multiple staging of pumps. Numerous wear resistant materials have been tried for pump liners and impellers. For small rounded particles the most successful appears to be rubber (10 to 20 times the life of steel) whilst for large sharp cornered particles nickel steel (Ni-hard) and high chrome cast iron have proved popular with lives some four times steel (Want, 1980). Pump casing pressures have been rising steadily and a number of projects are currently using six centrifugal pumps in series to achieve pressures of around 4.5 MPa. The present limit appears to be around 5.2 MPa (Ghandi et al, 1980).

For very high pressures positive displacement pumps are necessary. In this case the emphasis has been on reducing wear rates of wetted parts by better design of valves (e.g. Patton, 1981) and by use of water flushed plunger pumps (Null, 1982). However normal piston and plunger pumps are limited to a maximum particle size of around 6 mm due to valve closure problems. A number of means of overcoming this have been developed such as the Hitachi hydrohoist (Sakamoto, 1974) and other pipe feeder (Kocsanyi, 1972) and lockhopper types (Thompson et al., 1972). The main disadvantage of these are the relatively sophisticated control systems which are needed to open and close the slurry valves.

An alternative approach is to use rotary feeders whereby valve operation is achieved by fast rotary valves. Any coarse particles impeding valve closure are smashed. Examples are the Kamyr rotary injector (Funk et al., 1978) and the Boyle rotary pump (Stewart, 1972). In the concrete industry the peristaltic pump has proven popular for medium pressure applications.

Pipe wear is also a serious problem with coarse particle slurries, not only because of the coarse particles but because of the high velocities involved. To try and reduce pipe wear rates many different lining materials have been tried, among them wood, basalt, rubber, cast iron, polyurethane and asbestos. Probably the most successful has been polyurethane for which reported wear lives have been 8 to 20 times steel (Sambells, 1974, Rouse, 1982).

Much of the above discussion has been concerned with hardware developments to improve pump and pipe performance of coarse particle, settling slurries. Despite these improvements, the transportation of coarse particle heterogeneous slurries is still essentially limited to relatively short distance applications. Nevertheless there is still a place for this mode of operation and several installations have demonstrated the advantages of these slurry handling applications over more conventional means of handling the material. Noteworthy examples include the hydromining and hydraulic hoisting of coal from a mine to the surface or coal preparation plant, for example in West Virginia (George, 1982); the transport of coal from a storage stockpile to a ship loading facility as proposed for the Staten Island coal export terminal (Orr and Thompson, 1982) and the slurry loading of coal from a port storage facility to a large ship via a submarine pipeline and single point mooring (Faddick, 1982, Rigby et al. 1982).

An alternative approach for handling coarse particles has been to try and modify the behaviour of the slurry itself. The aim is to reduce the settling tendency of the coarse particles. One novel approach has been to use specially shaped pipes (Sauermann, 1982). Another approach which has created a lot of interest has been the so-called stabilized slurry. This has been of particular interest in regard to the pumping of coarse coal. It involves mixing the coarse particles with a proportion of finely ground particles. The latter form a viscous vehicle which reduces the settling tendency of the coarse fraction. The hope is that this will result in lower pressure gradients and pumping velocities. It should also allow simpler dewatering than finer coal slurries. Although it was first suggested in 1970 (Elliot & Gliddon, 1970) it has yet to be proven that it is commercially viable. There seems little doubt that provided the fine particle vehicle portion is made sufficiently viscous a stable slurry can be achieved (e.g. Duckworth et al., 1982, Rigby et al., 1982).

The question marks surround the resulting pressure gradients at economically viable coarse/fine ratios and the scale-up to large diameter pipes. At this stage it appears that roughly 50% of the coal needs to be less than 0.5 mm. Dewatering of this fraction presents the same problems as with conventional fine coal slurries. Given this fact, unless the pressure gradients can be reduced to near that of the fine coal slurries (which at present seems unlikely) the economics of the approach seem doubtful for other than some specialised relatively short distance applications. Technical problems may also exist concerning scale-up to large diameter pipes (Thomas, 1979, Rigby et al., 1982). These slurries are currently undergoing study in Australia both by the CSIRO and the BHP/BPA IPTACCS group. The CSIRO, in co-operation with the R.W. Miller Coal Company, is currently constructing a 300 mm diameter test loop at Minmi near Newcastle. When this loop begins operation the future of the stabilized slurry approach may become clearer.

This approach of using mixtures of coarse and fine solids could have a potential application in the disposal of overburden material mixed with fine tailings slurries from mineral processing operations. In this case relatively short distances would be involved.

An alternative method of achieving a non-settling slurry has been proposed by Cowper et al. (1982). This involves use of fine magnetite to achieve a vehicle of density equal to the coal. Thus the settling tendency of the coarse coal is prevented, not by the viscosity of the vehicle as in the case of stabilized slurries, but by neutral buoyancy. This approach has the potential advantage of very low pressure gradients, similar to fine particle slurries, but has the disadvantage of requiring a return pipeline to recycle the vehicle. It is being actively studied in Australia by Slurry Systems Pty. Ltd. of Sydney.

4 ENERGY SLURRIES

4.1 Coal Oil Mixtures (COM)

The rapid rise in the cost of oil in the past decade has spurred interest in the use of coal slurries as fuels. Although in Australia most electricity is generated by burning coal, such is not the case overseas especially in the USA and Japan. In these countries a large proportion of the electricity is generated in oil fired stations. These boilers cannot easily be modified to burn coal as a solid fuel, hence the interest in substituting oil with a coal slurry. Other possible areas of application include injection of COM into blast furnaces, open hearth furnaces and lime and brick kilns. Initial interest centred on coal-oil mixtures typically in the ratio 50% coal to 50% oil. To achieve a stable mixture the coal must either be ground extremely fine or else a chemical stabilizer employed. A number of demonstration projects have proven the technical feasibility of COM technology (e.g. Gilbert & Jackson, 1981), however to date commercial applications have been limited to relatively small scale operations.

The utilisation of coal-oil mixtures containing extremely finely ground coal (so called "micronised" coal, with a particle size below 10 microns) has been suggested for use in diesel engines (George, 1982). This fine grinding together with the removal of impurities in the coal offers the potential for a clean fuel. Whilst it has been demonstrated that this type of slurry can be burnt in diesel and gas turbine engines, micronised coal slurry requires further investigations to optimise grinding and preparation costs and to evaluate the commercial viability of the process.

4.2 Coal Water Mixtures (CWM)

Because of the apparently debatable economics of COM, research has recently switched to direct firing of coal water mixtures. In this case all of the oil is substituted by coal so the savings in fuel costs are roughly twice the savings resulting from use of COM. It is easier to achieve a stable CWM than is case with COM and generally no stabilizer additive is necessary. Indeed the reverse is the case in that much research has centred on viscosity reducing additives so that the solids concentration can be increased. Without any additives viscosity considerations generally limit the coal concentration to about 60% by weight. With additives the concentration of coal can be increased to around 75%. About 3 to 5% of the thermal energy of the coal is used in vaporizing the water. Henderson & Schaffee (1981) claim that the cost of converting coal to CWM is between $25 to $30 per tonne. The resulting price per unit of thermal energy is about one half that of oil.

Whilst the economics of CWM's would appear to be favourable there are many problems to be overcome before they will gain widespread acceptance. Among them are the extent of boiler de-rating necessary, the long term reliability of equipment, environmental considerations and transportation costs of coal.

In the long term it holds promise as a viable replacement for oil, pumpable and transportable as a liquid fuel. In this regard a major disadvantage of CWM's is their high viscosities even with additives. For example, Henderson & Schaffee (1981) quote viscosities of between 0.60 and 3 Pa s. For economic pumping over long distances the viscosity needs to be an order of magnitude less. It can be noted here that typical No.6 fuel oil at room temperatures also has a high viscosity of around 1.2 Pa s but because its viscosity is very highly temperature dependent this can be reduced dramatically by heating prior to pumping. For example heating to 65°C will reduce its viscosity to around 0.1 Pa s. CWM's do not exhibit this strong temperature dependence and the viscosity can only be reduced by reducing the concentration. Thus the requirements of high thermal efficiency and low pumping costs are in direct conflict.

Combustion trials in test furnaces have shown that CWM can be burned stably without supplementary fuels. However carbon burn-out was somewhat less than that with the parent coal alone. Modifications to burner nozzle designs are required to overcome erosion problems and to provide effective atomisation (Scheffee et al., 1982).

4.3 Other Slurries

Coal-methanol slurries containing approximately 60% coal have been proposed as an alternative to other energy slurries for combustion applications. Such a fuel could contain minimum levels of sulphur and nitrogen and have highly favourable combustion characteristics. The scarcity and high cost of methanol, however would appear to limit such an alternative to areas where methanol could be produced at economically attractive costs (Bergman, 1982).

5 REFERENCES

BERGMAN, P.D., KIRKLAND, L. and GEORGE, T.J. (1982). "Why coal slurries stir worldwide interest". Coal Mining and Processing, p 34.

COWPER, N.T., VENTON, P.B. and THOMAS, A.D. (1982). "The application, potential, development and options for coal slurry pipelining in Australia". Proc. 4th Int. Symp. on Freight Pipelines, Atlantic City, U.S.A.

DAWSON, K. and SARGENT, M.A. (1975). "Energy transportation - A case study for the electricity supply industry". Prep. Thermofluids Conf., Inst. Engrs. Aust., Brisbane, Dec.

DAWSON, K., PERKINS, D.N., BILLINGTON, W.K., SWAIK, G. and LEGGO, J. (1980). "Energy transport - A case study for the electricity supply industry". State Elec. Comm. of Qld., Report No. SECQ-072, June.

DUCKWORTH, R.A., PULLUM, L. and COCKYEAR, C.F. (1982). "The hydraulic transport of coarse coal at high concentration", Proc. 4th Int. Symp. on Freight Pipelines, Atlantic City, U.S.A.

DERAMMELAERE, R.H., DINA, M.L. and McEWAN, P.G. (1982). "ETSI Coal Evaluation Plant", Proc. 7th Int. Tech. Conf. on Slurry Transportation, Lake Tahoe, U.S.A., p 27.

ELKES, G.J., RIGBY, G.R., SIMSON, H.A. and MAINWARING, D.E. (1982). "Integrated coal upgrading and slurry transport". Prep. 10th Aust. Chem. Eng. Conf., Sydney, p 109.

ELLIOTT, D.E. and GLIDDON, B.J. (1980). "Hydraulic transport of coal at high concentrations", Proc. Hydrotransport 1 Conf., Coventry, England, 1980, p G2.

FADDICK, R.R. "Shiploading coarse-coal slurries" (1982). Proc. Hydrotransport 8 Conf., Johannesburg, South Africa, p 37.

FUNK, E.D., BARRETT, M.D. and HUNTER, D.W. (1978). "Pilot experiences with run of mine coal injection and pipelining", Proc. Hydrotransport 5 Conf., Hanover, Germany, p F3.

GEORGE, T.J. (1982). "Expanding the role of coal slurries", Coal Mining & Processing, Nov., p 42.

GHANDI, R.L., SNOEK, P.E. and CARNEY, J.C. (1980). "An evaluation of slurry pumps", Proc. 5th Int. Tech. Conf. on Slurry Transportation, Lake Tahoe, U.S.A., p 267.

GILBERT, B.F. and JACKSON, G.E. (1981). "Coal oil mixture experience at Florida Power and Light Company", Proc. 6th Int. Tech. Conf. on Slurry Transportation, Las Vegas, U.S.A. p 226.

HENDERSON, C.B. and SCHEFFEE, R.S. (1981). "The development of coal oil slurries as a boiler feed", Proc. 6th Int. Tech. Conf. on Slurry Transportation, Las Vegas, U.S.A., p 218.

KENNETT, E.R. (1981). "The growing viability of continuous systems for the transportation of coal", Coal Trans. Conf., C.S. Publications Ltd., London, UK, Sept. 29-Oct. 1.

KOCSANYI, L. (1972). "High pressure hydraulic transport for coal and other mining materials", Proc. Hydrotransport 2, Coventry, England p H4-69.

MONTFORT, J.G. (1982). "Operating experience of the Black Mesa pipeline", Proc. 7th Int. Tech. Conf. on Slurry Transportation, Lake Tahoe, U.S.A., p 421.

NULL, L.G. (1982). "Plunger flush systems", Proc. 7th Int. Tech. Conf. on Slurry Transportation, Lake Tahoe, U.S.A., p 113.

ORR, L.P. and THOMPSON, T.L. (1982). "Staten Island Coal Export Terminal". Bulk Solids Handling, 2,4, p 661.

PATTON, A.J. (1981). "Valve design for slurry systems", Proc. 6th Int. Tech. Conf. on Slurry Transportation, Las Vegas, U.S.A., p 184.

PIKE, D. (1982). "Coal transport - an analysis of technical and economic factors". The Financial Times Business Information Ltd., London.

RIGBY, G.R. and CALLCOTT, T.G. (1977). "Pipelining coking coals", BHP Tech. Bull., 21, 2, p 2. Nov.

RIGBY, G.R. (1982). "Slurry pipelines for the transportation of solids". Mech. Eng. Trans. Inst. Engrs. Aust., ME7, No.3, Sept. p 181.

RIGBY, G.R., JONES, C.U. and MAINWARING, D.E. (1983). "The potential for coal slurry transportation and beneficiation operations in electricity generation", Prep. Inst. Engrs. Aust. Eng. Conf., Newcastle, p 92.

RIGBY, G.R., JONES, C.U., MAINWARING, D.E. and THOMAS, A.D. (1982). "Slurry pipeline studies on the BHP-BPA 30 tonne per hour demonstration plant", Proc. Hydrotransport 8 Conf., Johannesburg, South Africa, p 181.

ROUSE, W.R. (1982). "Operating experience with a residue disposal system". Proc. Hydrotransport 8 Conf., Johannesburg, South Africa, p 77.

SAKAMOTO, M. (1974). "Development of hydrohoists; Slurry feeders without contamination", Proc. Hydrotransport 3 Conf., Golden, U.S.A., p A1.

SAMBELLS, D.F. (1974). "A practical solution to pumping an abrasive slurry", Proc. Hydrotransport 3 Conf., Golden, U.S.A., p J1-7.

SAVERMANN, H.B. (1982). "Hydraulic transport of coarse solids in circular and segmented pipes", Proc. Hydrotransport 8 Conf., Johannesburg, South Africa, p 51.

SCHEFFE, R.S. et al. (1982). "Coal water slurry as utility boiler fuel". EPRI Report CS-2287.

STETLER, J.J. (1982). "Samarcos Iron Ore Slurry Pipeline Transportation System", Mining Eng., Oct., p 1466.

STEWART, D.B. (1972). "High head slurry pump", Proc. Hydrotransport 2 Conf., Coventry, England, p H6-93.

THOMAS, A.D. (1979). "Pipelining of coarse coal as a stabilized slurry - another viewpoint", Proc. 4th Int. Tech. Conf. on Slurry Transportation, Las Vegas, U.S.A., p 196.

THOMPSON, T.L., FREY, R.J., COWPER, N.T. and WASP, E.J. (1972). "Slurry pumps - a review", Proc. Hydrotransport 2 Conf., Coventry, England, p H1-1.

VENTON, P.B. (1982). "The Gladstone Limestone Pipeline", Proc. Hydrotransport 8 Conf., Johannesburg, South Africa, p 49.

WANT, F.M. (1980). "Centrifugal slurry pump wear - plant experience", Proc. Hydrotransport 7 Conf., Sendai, Japan, p 301.

WASP, E.J. (1982). "ETSI to Date", Proc. 7th Int. Tech. Conf. on Slurry Transportation, Lake Tahoe, U.S.A., p 5.