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Hydrotransport in Coal Mines

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Hydrotransport dans les mines de charbon
Hydrotransporte en minas de carbón
炭鉱における水力搬送
煤矿场的水力运输
النقل الهيدروليكي في مناجم الفحم

Hydrotransport in Kohlengruben

Der Einsatz von Wasser als Trägermedium für Kohle gehört zu einer Technologie, die in der Bergbauindustrie noch weitgehend unbekannt ist. Hydrotransport kann in flacher Lagerung, bei einfallenden Flözen und in der Schachtförderung eingesetzt werden. Der hydraulische Transport im Kohlebergbau erhöht die Sicherheit und die Wirtschaftlichkeit, erfordert jedoch ebenfalls die Bewältigung großer Wassermassen und einen höheren Energieaufwand, um Kohle gegen die Schwerkraft zu befördern.

Hydrotransport dans les mines de charbon

L'utilisation de l'eau comme milieu porteur pour le charbon appartient à une technologie qui est encore largement inconnue dans l'industrie minière. L'hydrotransport peut être utilisé dans le stockage à plat, dans les veines en pente et dans l'extraction par puits. L'hydrotransport dans l'exploitation des mines de charbon augmente la sécurité et la rentabilité, mais exige cependant le contrôle de grandes masses d'eau et de grands frais d'energie pour transporter le charbon contre la pesanteur.

Hydrotransporte en minas de carbón

La aplicación de agua como medio portante para carbón es una tecnologia poco conocida en la industria minera. Hydrotransporte puede ser aplicado, tanto en secciones horizontales, en capas incidentes y en la extracción por pozos. El transporte hidráulico en la minería del carbón eleva la seguridad y la rentabilidad, exije al mismo tiempo el dominio de enormes masas de agua y gastos más elevados de energía para poder transportar el carbón contra la gravitación.

Summary

The utilization of water as a transporting medium for coal belongs to a section of technology which is still unfamiliar to large sections of the mining industry. As a function of direction of the hydraulic flow to gravity, hydrotransport can be classified into three groups:

1. Hydrotransport in the direction of gravity as applied to inclined coal seams: Water-solids mixture movement can be along the mine floor, in flumes or pipes.
2. Hydrotransport at zero gravity as applied to flat coal seams and drift mining: Slurry movement is in pressurized pipes for face, mine and long distance haulage.
3. Hydrotransport against gravity as applied in shaft mining: Coal transport can be by direct pumping, hydrolift, pipe-feeders, or by combined hydraulic and mechanical transport.

Hydraulic transportation in coal mining contributes to safety and mine economics, but also requires handling large quantities of water and larger energy consumption to move coal against gravity.

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1. Introduction

The technology of coal extraction does not influence the definition of hydraulic mining, because a hydraulic mine is one which is designed and equipped for the hydraulic transport of the mineral from the working faces to the surface.

Hydraulic coal transportation is a process which is borrowed from the technology of the hydraulic flow of solids, which is still under continuous development [1]. The hydraulic flow of coal can be by two principle regimes of fluid mechanics:

1. *Saltation regime:* This regime considers coal particles in the size range greater than 2.50 mm, and the particles are alternately lifted by the fluid and deposited on the pipe.
2. *Heterogeneous regime:* This regime considers coal particles in size between 0.25 and 2.50 mm, and the particles have a turbulent flow.

In underground coal mining the hydraulic flow of coal can be either in the direction of gravity, at zero gravity, or against gravity; each of these systems is detailed separately below.

Practical experience and competence in the use of hydrotransport systems for coal transportation is not widespread and the technology involved is still being developed at various research establishments, in particular, the United States Bureau of Mines, Steinkohlenbergbauverein (Essen), and the All Union Research and Development Institute for Hydraulic Coal Mining (Kuznetsk).

2. Hydrotransport in the Direction of Gravity

The main characteristic of hydraulic coal transportation in the direction of gravity is the inconsistency of flow of the water-solid mixture [2]. This is influenced mainly by the coal production processes and the underground mine situation of inclined seams, for example:

— Capacity and coal production rate per unit time varies, so that coal feed for transport is not constant.
— The water-coal ratio is inconsistent.
— Rock dilution of the water-coal mixture is not uniform.
— Friction coefficients vary.
— Gradient of flumes of pipes could be irregular.
— Open flumes change resistance at bends or constrictions which in turn alters velocity, etc.

For these reasons many derived equations based on the principles of fluid mechanics postulated to represent the behaviour of water-solids mixture under different motion conditions are not therefore valid [2]. In such cases the design elements have to be inferred from experimental investigations or trials actually on site in the mines, where particular consideration should be given to the following variables and parameters:

— Roadway and entry inclination.
— Choice of the flumes or pipes.
— Coal particle size distribution.
— Bulk material quantity and related water-solid ratio.
— Shape and size of flume or pipe.
— Lining material for the flumes and pipes.
— Water-solids mixture viscosity.

Gravity hydraulic transport systems can be designed using one of three basic concepts:

2.1 Mine Floor

Usually applied in the face area of the mine where coal flushing out is integrated with hydrotransport (Fig. 1).

Fig. 1: Artistic concept of hydraulic coal breaking and flushing out

Particular consideration in design should be given to the gradient and lithology of the mine floor and the size distribution of broken coal [3]. The rock type of the mine floor must, of course, be hard and be unaffected by water. Size distribution of coal lumps directly relates to water consumption. For example, if the gradient of the mine floor is 10° and the particle size of coal —70 mm, then the water requirement is typically up to 70 m³/h. However, if the particle size of the coal is —200 mm, then the water requirement is increased typically up to 250 m³/h.

2.2 Flumes

This is the most extensive type of gravity hydraulic transport, where capacity and economics are delineated by the character of the flumes, their gradient and the size distribution of the coal particles. For example, early flumes at Kaiser's mine in Canada [4] were installed at gradients up to 7°, which resulted in coal blockage. However, with the installation of flumes lined with a special low friction plastic at a grade of 4°, coal blockage has been eliminated, water-coal ratio by weight has been improved to 1:1, and annual transportation capacity has been increased by 1 million t of coal. The successful hydraulic transport of coal at Kaiser's mine is also influenced by the particle size reduction of the coal down to 200 mm, by a feeder breaker, which simultaneously regulates the flow of coal in the flumes [4].

2.3 Non-Pressurized Pipes

This type of transport is primarily used in steep pitching coal seams in order to move the water-coal mixture from the extraction area through rises to lateral haulage. The angle of pipe inclination can be between 30° and 80°, although this depends on the gradient of rises. At Mitsui's mine, for example the pipes for gravity transport are installed in the rises at 45° and in the haulage system with a 1° gradient [5]. To achieve movement of the water-coal mixture in haulage requires crushing of the coal to —3 mm and increasing the quantity of water (water-solid ratio 3:1).

Coal transportation in the direction of gravity is the major advantage of hydraulic mining.

3. Hydrotransport at Zero Gravity

Hydraulic coal transportation at zero gravity is through the utilisation of a pressurized pipe system, where slurry movement is by piston or centrifugal pumps. This type of hydrotransport is implemented in horizon mining systems, that is as well as in drift haulage and surface transportation. Mechanized coal extraction and in the majority of cases, mechani zed coal loading, offer relatively regulated conditions for slurry flow, but certain irregularities are present:

1. Variances in coal feed in the pipelines due to changes of the rate of coal excavation.
2. Existence of coal particles in a wide range of sizes.
3. Inconsistency in rock dilution.

The above irregularites and other minor influences require that the theory of hydrodynamic flow applied to coarse coal has in consequence to be adjusted. This is best achieved by introducing empirical equations, parameters and guidelines which describe such a flow, and which can also be utilised for hydrotransport evaluation. For example:

— Reduction of coal particle size in relation to the pipe diameter. Maximum particle size should be 1/3—1/4 of diameter. (In the USA, coal sizing is up to 50 mm, in view of the fact that 80 % of the coal produced by the miner is less than this size [6]).
— Capacity and head losses of the pump needed to evaluate slurry velocity.
— Relationship between slurry velocity and transportation capacity.
— Handling of large solid particles and also relatively small particles at high volumetric capacity, etc.

Centrifugal pumps are more favourable to achieve optimal values of hydrotransport. However, a shortcoming is their inability to produce high heads which directly effects transportation capacity. The solution to such a problem might be to install additional pump stations at appropriate spacings or to install pumps in series.

In relation to underground mine infrastructure, the transport of a water-coal mixture by pressurized pipes can be classified into three systems:

3.1 Face Haulage

The main characteristics of this system are the feeding of the coal in pipes and extension of these pipes to follow each advance of the continuous miner. At the present time two coal feeding designs have been implemented. Firstly, a system which involves the injection of coal into a high pressure waterline, by a suction method, so that coal does not pass through any pumps; this results in less particle degradation and allows for higher pump efficiency. Secondly, mechanized coal feeding in sequences: miner — shuttle car — feeder breaker — hopper and screw feeder with continuous water addition, where the pump combines the water-coal mixture at a ratio 3:1 (by weight) as illustrated in Fig. 2. Extension of the pipes can be achieved by use of Chicson couplings, which fold the pipe like a pantograph (Fig. 2) or by 25cm diameter rubber hoses mounted on wheels, which are replaced by steel pipes after a 330m advance [6].

3.2 Mine Haulage

This system represents the main hydrotransport line within which coal is discharged from the flumes or pipes and from working places and sub-haulages. If the mine is located above drainage level then the hydraulic transport line continues on ground surface to the washing plant [7]. Produced coal has coarse particle sizes which typically require high velocities to avoid coal deposition and plugging. There is also a necessity for centrifugal pumps to have large clearances. Typical requirements are to move 30 % or more weight coal at 3—5 m/s causing friction losses as much as 0.5 MN/m² per km and requiring two centrifugal pumps in series per 2 km. Pumping coarser slurries requires more energy and more frequent pump replacement. Overhaul due to extensive wear takes place typically every two months [8].

3.3 Long Distance Haulage

In this case the hydrotransport systems replaces coal transportation methods which utilise railway cars [9]. Maximum coal sizes are typically up to 1.5 mm, where solid particles form a slurry of 50 % solids by weight. The slurry velocity is 1.6 m/s and this type of hydraulic transportation causes size degradation. For example, at Jubilee Mine (USSR) in a 12 km pipe transport, at entry there was 18 % —1 mm coal particles while at the exit this became 42 %. However, pressure losses in the pipeline are somewhat lower, so the spacing of pumps can be at larger distances [9]. In the foreseeable future and with particular reference to coal mining there is expected to be a substantial increase in the utilisation of hydraulic transportation by slurry piping methods, mainly because of the low cost advantage and the fact that environmental requirements can be better accommodated by this system.

4. Hydrotransport against Gravity

The hydrotransport of coal against gravity is practiced in shaft mining, where coal has to be hoisted from underground to the surface [8]. The majority of hydrohoisting systems are similar to long distance haulage hydrotransport, where a water-coal mixture has to be prepared before being injected into the pipes. This is usually done in two stages:

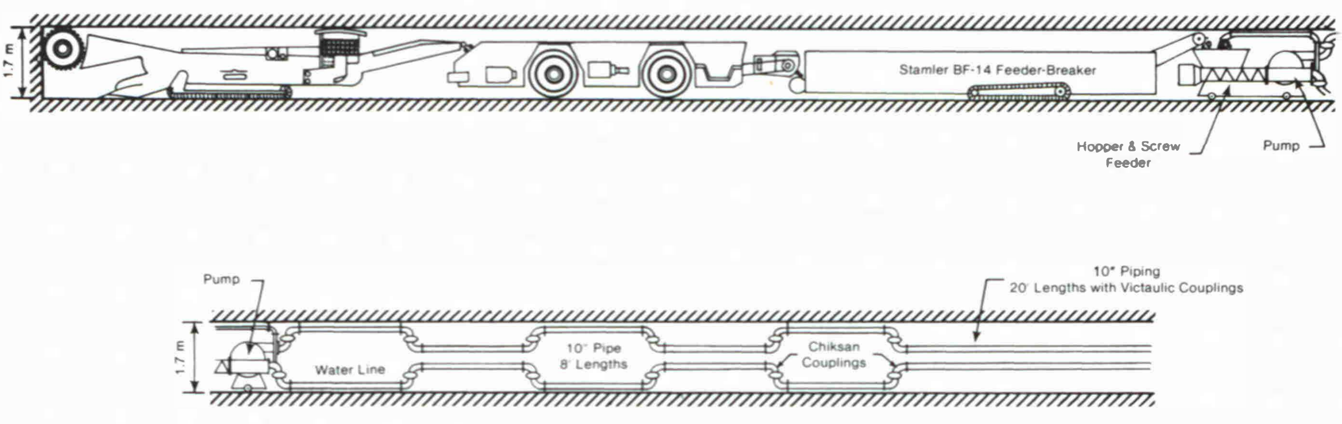

Fig. 2: Elements of hydraulic face haulage transport

1. *Crushing and screening plant,* where the coal has to be reduced to the particle size distribution defined by the pumping system design specification. For example, at Hansa Mine in West Germany, crushing and screening of the coal is to —1 mm, which is that required by the slurry piston pumps.
2. *Pumping station,* which consists mainly of an extensive area of water sumps. For example, at Jubilee Mine (USSR) there are 3 sumps with a total capacity of 450 m³ water, which are used for producing slurry with a water-solid ratio at 7:1 [9].

At the present time there are available several developed methods for the transportation of coal from one level to another higher elevation, and these are briefly described below:

4.1 Pumping Method

In West Germany coal hoisting by pumping has been undertaken by centrifugal slurry pumps with large open passages (a simple method, but limited to a vertical head of 200 m), and piston pumps operating at high pressure. Piston pumps are not entirely satisfactory because of certain reported valve problems and limitation to pumping only coal fines. To achieve the necessary height in hydrohoisting, pumping is balanced by a multiple stage series of pumps [10]. In the USSR, two stages of centrifugal pumps have been applied which were capable of pumping coal with a particle size distribution up to 70 mm against a total head of approximately 450 m.

4.2 Hydrolift System

This is the most successful method of coal hydrohoisting, but is also the most expensive. For example, the shaft depth has to be extended by typically 20—50 % of the effective hoisting length to accommodate a deep sump for the injection of the slurry into the pipes (Fig. 3). At the Read Army Mine [9], compressed air at a pressure of 1.2 MN/m² is introduced at a point 20 m above the sump floor at the rate of 300 m³/h and it is discharged from the slurry at an air separator 40 m above ground level. The air lifting capacity is 900 t/h coal with an effective head of 320 m [9].

4.3 Pipe Feeder Method

In the USSR several techniques have been developed to lift coal which utilise high pressure clean water (supplied via multiple stage centrifugal pumps) with limited head.

The most common technique is with the supply water fed through valves to one of three horizontal pipes each approximately 100 m long. The pipes are filled in rotation by very low head centrifugal slurry pumps. By phasing the valves, the water serves to drive out the coal slurry into the rising main. As the slurry is hoisted, the water present in the filling section of the pipe is fed off back to a sump for re-use in a high pressure pump [10].

4.4 Combined Hydro/Mechanical Hoisting

This method requires that the coal has to be separated into fines and coarse particles, additionally the coarse coal should be dewatered. The fines are hoisted hydraulically, but the coarse coal cannot be accommodated and is therefore transported mechanically. The cut-off coal particle size between fines and coarse depends on the undergound installations for coal sizing and dewatering. For example, at the hydraulic mine of Kaiser Resources Co., there is a central plant for coal sizing and dewatering, where fines are screened up to 0.75 mm (35 % of run-off-mine coal), and hoisted hydraulically by a one stage centrifugal pump, but the rest of the coal is dewatered and transported by belt conveyor to ground surface [2]. However, at the hydraulic mines of Mitsui Mining Co., the cut-off size is 3.0 mm, where the station for coal sizing and dewatering is adjacent to the extraction panel. Locally, from each adjacent panel, the coarse coal is transported to the shaft by belt conveyor, and the slurry of fines is piped to a central sump. From the sump, the coal slurry is pumped by Mars piston pumps through a lift of 200 m to the main sump, whence it is pumped to the surface in stages by centrifugal pumps. This combined method of coal hoisting is becoming more attractive because of less coal degradation and less water consumption for transport against gravity [5].

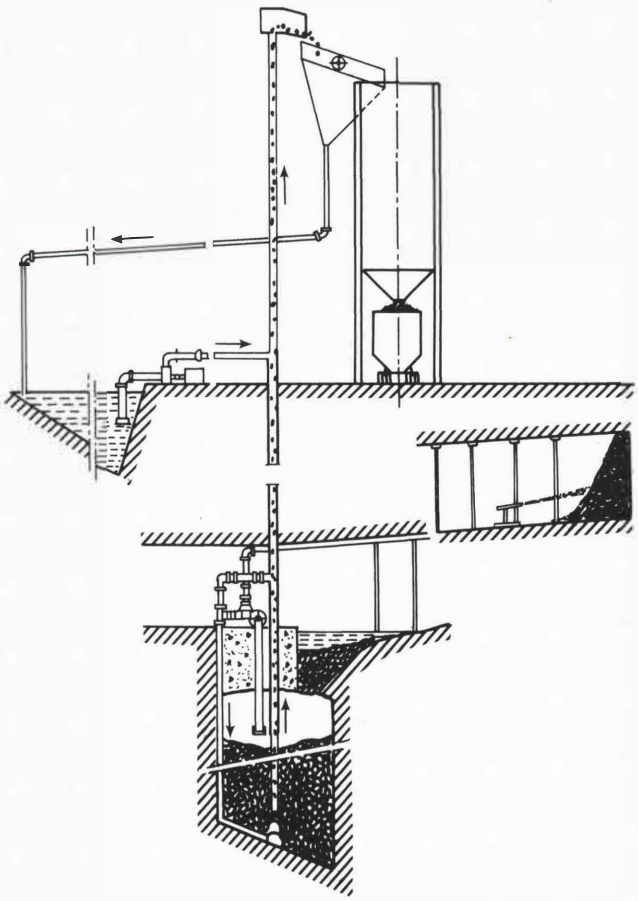

Fig. 3: The Hydrolift integrated with hydraulic mining

The hydraulic transport of coal in shaft mining is more expensive than conventional mechanical hoisting [9].

5. Conclusions

When comparison is drawn between mines that employ conventional modes of coal transportation and hydraulic transportation mines, the following advantages are evident:

— The coal production with hydraulic coal haulage can be 50 % higher than with a conventional shuttle car system.

— The cost of hydraulic transportation of coal in direction of gravity might be only 10% of the mechanized transport, however, the relative cost of coal transportation against gravity in hydraulic mining can be doubled in relation to conventional hoisting.

— Hydrotransport eliminates 75% of accidents registered in conventional underground coal mining, also, the safety is increased by bringing to a minimum the possibility of a catastrophic ignition of gas or dust as well as offering reduction of airborn dust and better underground climate conditions.

— The main disadvantage of hydrotransport is handling large quantities of water, which have to be cleaned and recycled.

The hydraulic coal transportation in the mining industry has been developed to the level where it can be satisfactorily designed and applied to handling mined out coal either by mechanized technology or by water jet technology.

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