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APPLICATION OF DEEP DIAPHRAGM WALLS FOR GROUNDWATER CONTROL IN OPENCAST LIGNITE MINING IN THE GERMAN DEMOCRATIC REPUBLIC

by
Dr-Ing Werner Mielcarek
V.E. BRAUNKOHLENKOMBINAT,
SENFTENBERG
GERMAN DEMOCRATIC REPUBLIC

Abstract

In the German Democratic Republic, about 95% of highly saturated lignite deposits, mined by opencast mining methods, are drained by dewatering wells. However, in order to reduce the surface water inflow to an excavation through sub-soil and to minimize the number of dewatering wells and to effect financial and material savings deep impermeable diapaphragm walls are being increasingly used. In order to meet the requirements of modern opencast mining technology, these diaphragm walls are some 100m deep and extend for a continuous length of several kilometers. Consequently, the well known technique of constructing diaphram walls by the discontinuous pile and section method has been replaced by the newly developed continuous leading pile method.

As a result of research and development, this new method of excavating deep trenches utilises a horizontally rotating twin screw shaft device. This technique can excavate a trench in soil from the surface to its final depth by continuously advancing in a lateral direction. Two further technical modifications to this device have been carried out to improve its operational efficiency. The paper describes the application of deep diaphragm walls in the control of groundwater in opencast lignite mining.

TECHNIQUES OF MINEWATER CONTROL IN OPENCAST LIGNITE MINING IN THE GERMAN DEMOCRATIC REPUBLIC

In the G.D.R., lignite plays an important role as a primary source of energy, i.e. for generating electricity, heating and as a domestic fuel. In 1986, it was planned that the annual output of lignite should be increased from 310 M tonnes per annum to 330 M tonnes per annum in 1990. The lignite deposits of the G.D.R. are exclusively of the Tertiary origin. These deposits occur between thick beds of confined and unconfined aquifers. In the Lusatia Lignite district, which is located at about 80 to 130 kilometers south to the south-east of Berlin and includes the townships of Senftenberg, Hoyerswerda, Forst, Cottbus, Luebbenau and Lauchhammer special ground water problems exist. This is due to the presence of remnant glacial spillways which intersect a large space from the east to the west through gravelly and sandy cap rock of the lignite deposits. The existing and planned open pit mining operations in the Northern part of the Lusatia District, which are in close proximity to the townships of Forst Cottbus and Luebbenau are located within the Glogov-Baruth Glacial Spillway which extends from the Polish border to the South of Berlin. This presents a serious ground water problem because the expected amount of water entering the surface mines will substantially surpass the output of lignite by several orders of magnitude.

In the Jaenschwalde opencast mine located in the eastern most part of the mining district ground water causes particular difficulties because of cost effectiveness as additional water enters the mining excavation through the sub-soil from the river Neisse. The total amount of water produced from all opencast sites in the G.D.R. was 1650m Cubic Metres in 1985 and this is expected to rise to 1800 m cubic metres in 1990. This amounts to 5.3 cubic metre and 6.0 cubic meters of water raised per tonne of lignite mined respectively.

In the past 20 years, the majority of opencast dewatering has been carried out by dewatering wells and the total length of wells drilled amounts to 220,000 m per year. According to their average depths, the annual number of wells to be drilled, installed and connected to the draining system ranges from 2200 to 2500 . Although the average depth of these wells is expected to increase and the geological and hydrogeological conditions are expected to deteriorate, dewatering by means of borehole wells will remain the most dominantly used method in the next two decades. Hence it follows that the application of deep diaphragm walls will not lead to a fundamental change in opencast mine drainage policy, but will remain as a reasonable complementary technique to the existing deep borehole method. The paper describes two practical examples of the application of deep diaphram walls in controlling surface water inflow to surface lignite mines.

The first application of this technique is related to the Jaenshwalde opencast lignite mine in the eastern border of the GDR where a deep diaphragm wall has been applied to a sloping unconfined aquifer to reduce substantially the amount of water pumped from the dewatering wells. As a consequence of the large scale geotechnical research carried out in the 1970's, it was decided to applya deep diaphragm wall to prevent the inflow of water from an unconfined aquifer (in sub-soil) to the proposed surface mining excavation. Similarly, there are plans to control an excessive inflow of groundwater from an unconfined aquifer continuously recharged by the river Neisse at the Berzdorf opencast mine by the application of the deep diaphragm wall. This mine is located 150km south of Cottbus in the Upper Lusatia district and belongs to the lignite mining complex of Oberlausitz.

DEEP DIAPHRAGM WALLS FOR OPENCAST MINE DRAINAGE

For the past 20 to 30 years, the civil engineering construction industry and water engineering industry has made use of deep diaphragm wall for the control of ground water when constructing of foundations, sealing walls and earth dams. Inspired by this basic development, the lignite mining industry in the GDR started to explore the potential application of the diaphragm wall to opencast mine drainage. During this period, the V.E. Braunkohlenkombinat Senftenberg in cooperation with the Freiberg Mining Academy commenced a basic research programme into the techno-economical feasibility and hydrological research in the application of the diaphragm wall in opencast mine dewatering. With regard to opencast mine dewatering the diaphragm walls have to meet the following criteria:-

- o Diaphragm walls have to penetrate through all the layers of sedimentary strata of the pleistocene and tertiary periods consisting of sand, gravel, boulders, clay, silt and lignite and has to pierce at least 1500mm into the solid bed-rock.
- o The required depths of diaphragm walls will range upto 100m and their horizontal length is expected to exceed several kilometers.
- o Sealing wall operations should be efficient and cost effective in comparison to other existing ground water control methods.

Because of the limited tecnical know- how of deep diaphragm wall construction at the present moment, all the above requirements can not be fully met. For this reason it has been necessary to carry out further research in the field of Mechanical Engineering, Hydrology and Soil Mechanics associated with deep sealing wall construction. In the field of Mechanical Engineering, a twin screwshaft soil milling device has been developed which can work in conjunction with the suction type or the airlift typeof pumping equipment. Futher developments have been carried out to modify the milling device by adopting two distinct lines of approach as follows:-

- o Large diameter drilling techniques.
- o Development of a new milling device discussed in the following section.

Twin Screw- Shaft Milling Techniques

In the past fifteen years, the Lignite Mining industry of the GDR has developed mechanical equipment which is suitable to excavate deep soil trenches and to carry out simultaneous sealing operations. This development is based on the application of modern drilling techniques for large diameter dewatering wells and shafts in the Lignite Industry. This application was followed by the development of a new twin screw-shaft milling device as an accessory to the existing suction type drilling rig . The milling device is fitted with a hydro electro-mechanical drive, having an input power of 22 kwt. The horizontally rotating screw-shaft is armoured with cutting edges. In order to start the cutting operation, a borehole is initially drilled by means of the basic drilling rig. This borehole serves as a receptacle to guide the drive and bearings of the screw shaft.

The width of the trench when milled is 650 mm and the incremental cutting lengths reach upto 2.5m. The trench is milled outfor each incremental cut from the surface down to its final depth. The milled chips are transported bothby mechanical and hydraulic methods to the centre of the milling device, from where it is pumped to the surface through a suction type drilling pipe. The drilling pipe has a 150 to 200mm inside diameter and is attached to the milling device. On the surface the milled chips together with the drilling mud is discharged into a mud sump provided parallel to the axis of the trench. After separation of the chips by sedimentation process the drilling mud is recirculated to the trench. (Figure 1)

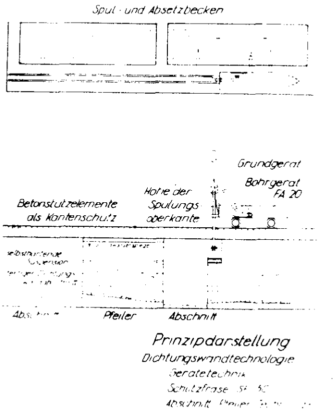
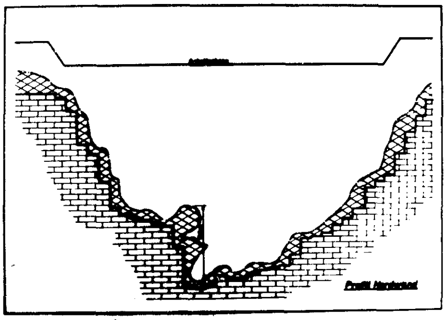


Figure 1. Diaphragm Wall Technique Type SF 50 /SF 30 Suitable for the Section Pillar Method.

- o Drilling Fluid and Sedimentation Basin
- o Basic Drilling Equipment type FA 20
- o Drilling Fluid Level
- o Edge Protection Concrete Element
- o Section
- o Pillar
- o Finished section of Diaphragm Wall

Based on the hydrogeological and physical properties of the soil, the level of water necesssary in a section of trench during milling operations and the maximum permissible length of the trench section to be milled in one operation are calculated by using the numerical methods. The viscosity and density of the drilling mud are important factors to ensure the stability of a trench section during its construction. Although, the milling operation within one section is continuous actual construction of the trench is carried out by the section-pillar method. This method involves milling out at least three sections of trench, and backfilling atleast two sections with a clay- cementaceous grout. After the grout has set, the intervening pillar in between the two sections is milled out and grouted. Thus, the sealing wall is continuously contructed along the full planned length of the wall by intermittent operations.

The design and layout of the milling device is such that the full depth and the full width of a trench section is milled in the direction of advance and subsequently grouted. The grout for this purpose comprises of drillingmud mixed with cement, sand and additives to form a homogeneous mixture. The grout is then poured or pumped through a stand pipe to fill a milled out section of the trench from the floor up to the surface. The quantity of the grout requirements are calculated taking into account the actual hydrogeological boundary conditions. The efficiency of the sealing wall operations can be quantified by expressing it in terms of the coefficient of permeability of the wall material. In practice a coefficient of permeability of the sealing walls of 10-10 to 10-12 m/s has been achieved.



Figures 2. Cross Sections of the Limestone Washout at the sites of the Northern Wall.

Applications of Sealing Wall and Results*-

The first trial application of deep diaphragm walls was in a limestone quarry where two proposed sections of the quarry were intercepted by a Glecigene erosion washout in a limestone rockmass containing an aquifer. The quarry had to cross this washout without any risk of water inflow in order to continue the mining of limestone immediately after the crossing. The cross-sections of the washout are shown in Figure 2 and Figure 3.

It should be noted that it was the first time a 45m deep diaphragm wall was constructed for groundwater control in a surface mining operation using a milling device. It should also be noted that the diaphragm walls were keyed to the foundations by penetrating 1.5 metres into the limestone bedrock.

One of the difficulties faced during the construction of the trenches was intensive wear of the cutting tool which resulted in a considerable loss of efficiency. Nevertheless, in the Pleistocene sediments a milling efficiency of 5.7 square metres per hour and in limestones that of 0.5 square metres per hour have been achieved.

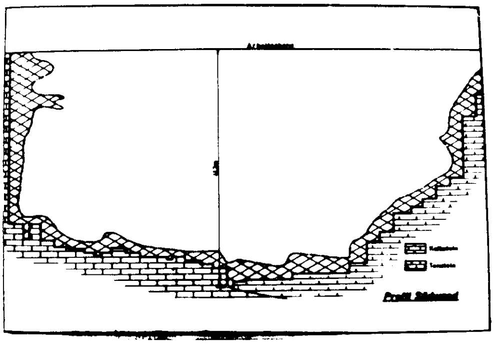


Figure 3. Cross-section of Limestone Washout at the Southern End

A futher project is now in progress at the Berzorf Open Pit Mine at Upper Lusatia where a separate grab unit, in conjunction with an improved Milling device SF 50 is being tried. This has been necessary because of the presence of boulders at a depth of 14 to 20 m, and also soil containing angular stones from 50 to 300mm in size, which can be excavated more efficiently by means of hydraulic grab units. [Figure 1 and 4].

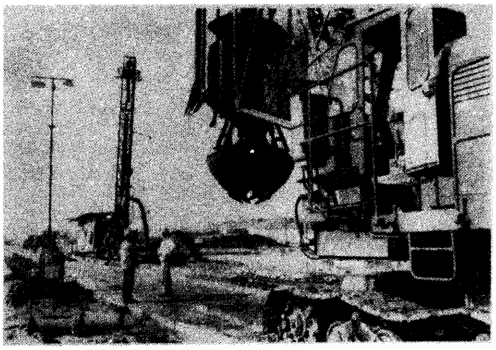


Figure 4. Soil Milling Device Type SF 50 and a Hydraulic Grab Unit type SG 60

Because of the higher sub-soil water table occurring at a depth of 0.5 to 1.0 m below the surface, an additional pressure of 0.5 bar had to be added to the drilling fluid to stabilise the trench during milling operations. For this purpose an embankment with a height of 4 metres had to be constructed. The total length of this diaphragm wall will be 6 to 7 kilometres and will be constructed in three stages. The foundation of this diaphragm wall is constructed in a thick tertiary clay layer lying at a depth of between 15 and 55 metres. As a consequence three track mounted milling devices type SF50 with three grab units running in line are being used in a highly coordinated manner to construct the diaphragm wall.

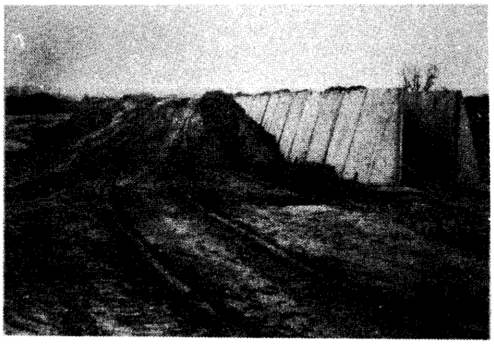


Figure 5. Embankment and Edge Protection Concrete Elements

The milling efficiencies achieved by the above mentioned milling system depends upon the type of strata available, which can alternate between sand and gravels, silt, clay, lignite and boulders. The milling rates through typical sand and gravel layers of up to 22 square metres per hour have been attained. In silt or clay horizons the milling rates range between 2 to 3 square meters per hour, but in boulder clay the milling rates are reduced to 0.2 to 0.5 square metres per hour.

The embankment section mentioned above, is stabilised in its upper section by concrete elements having a height of two metres to protect the edge of the trench from being damaged [See Figure 5]. These elements are reused again afer the drilling and backfilling operations in several sections of the trench are completed.

Twin Screw-shaft Milling Technique Types SG100 and SG 73.

In order to carry out sealing wall construction operations to the depth of 100 m, a new and sophisticated sealing wall rig has been developed. During the development of this technique, one of the major aims of the project was to develop a continuous trenching and back-filling operation. As a consequence of this project, a new Twin Screw-shaft milling device SG 73 capable of cutting a 1350mm widetrench was developed which has now been superceded by a new cutting head type SG 100.

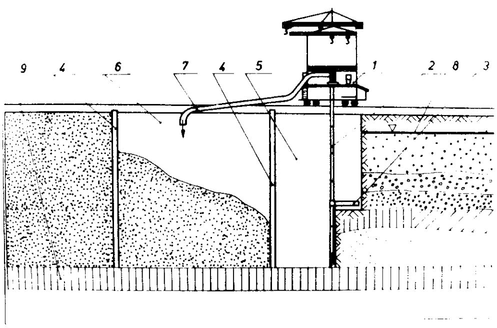


Figure 6. Continuous Cutting and Backfilling Operations in Diaphragm Wall Construction by SG 100 Rig

1- Milling Device Type SG 100
2- Leading Pile with hollow pipe
3- Twin Screw-shaft Milling (Cutting) device.
4- Concrete partition Segments
5- Milling (Cutting section)
6- Backfilling Section
7- Discharge Pipe Line
8- Sub-soil Water Table

9- Impermeable layer

The rig consists of a cutting head suppported by the rig gantry which in turn houses the mud circulation system, compressors, motor drives and a control room. The whole construction is mounted on a rail track. The SG 100 milling machine weighs 450 tonne, and is designed to cut slots to a width of 960 mm and to a depth of 100m.

Basically the milling device consists of a horizontally rotating twin shaft cutting device supported on a leading pile placed down an initial pilot hole. The cutting head can be moved vertically up and down by a cable winch on the leading pile. The cutting head cuts downwards, continously advancing towards the direction of projection of the sealing wall in 2m long sections. The basic principle of the diaphragm wall construction technique is shown in Figure 6. In order to start the trenching operations, a borehole 3 metres in diameter is drilled down to the final depth without using a casing. The pilot hole is filled with drilling mud and in this borehole hollow leading pile is installed. The pile carries out the function of supporting the cutting head and transporting the cuttings through the hollow pipe from the trench. The inactive part of the cutting device [guide block, gear and bearing] can freely run within the borehole.

Once a 2m long section of the trench has been cut out, the milling device is pulled up to the surface by the winch mounted on the gantry and the leading pile together with the cutting device is moved forward to a new position . The loose rock chips excavated by the milling head, are moved horizontally to the space already created by milling, and dropped near the sunction pipe of the pile at the floor of the trench. The slurry is then raised to the surface by airlift through the hollow leading pile and discharged to the surface sedimentation pond. Afterprecipitation of the chips the drilling fluid is recycled back to the excavation section of the trench. After milling out a length of trench of 50 to 70 metres, the back filling operation of the trench is started. Excavation and backfill sections of the trench are separated by means of cast concrete segment piles which are driven to the bottom into a impervious clay layer. The bottom most concrete segment is fitted with steel shoes which allow the concrete segment to penetrate well into the clay layer. Thus, the grout from backfill oparations does not leak to the excavation section of the trench and consequently, the cutting and backfilling operations can be carried out simultaneously. Moreover the completed section of the sealing wall can become functional as soon as the backfill is consolidated.

During excavation the trench section is supported by the pressure of the circulating mud. As the grout stands in the excavation it forms a layer of impermeable mass up to 6 cms in thickness in 24-48 hours. The permeability of this layer has been found to be in order of 1×10^{-9} m/s. After ensuring the formation of a sufficient thickness of the grout by calipre measurements or by checking with the nuclear gauges, the backfilling of the trench with the mixture of cuttings and mud-flush takes place to form the complete sealing wall.

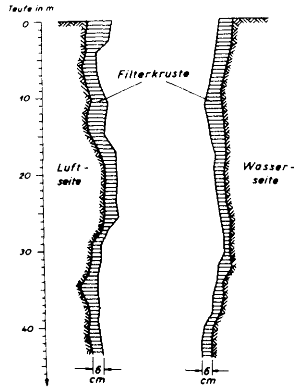


Figure 7. Cross Section of the Diaphragm Wall Showing the Thickness of Crust Agglomeration

- Incrustation
- Water intake side
- Dry Side
- Depth

CASE EXAMPLE: DIAPHRAGM WALL CONSTRUCTION AT THE JAENSCHWALDE OPEN PIT

The Jaenschwalde open pit mine expected an inflow of ground water from an unconfined aquifer and also lateral infiltration by surface water from the Eastern slope of the pit from the river Neisse . In order to protect the mine workings from the danger of water inflow through its eastern face, it was decided to construct a 6 km long and 100m deep sealing wall. The first stage of sealing wall construction comprised of 3.2 km of wall reaching to a depth of 100m , whilst the remaining 2.8 km length was expected to reach a depth of 130m.

The initial sealing wall operations were started with proto-type equipment SG73. However, in order to complete the project in a given time a larger and self-contained milling and backfilling rig incorporationg SG 100 cutting head was used. [Figure 8 and Figure 9]

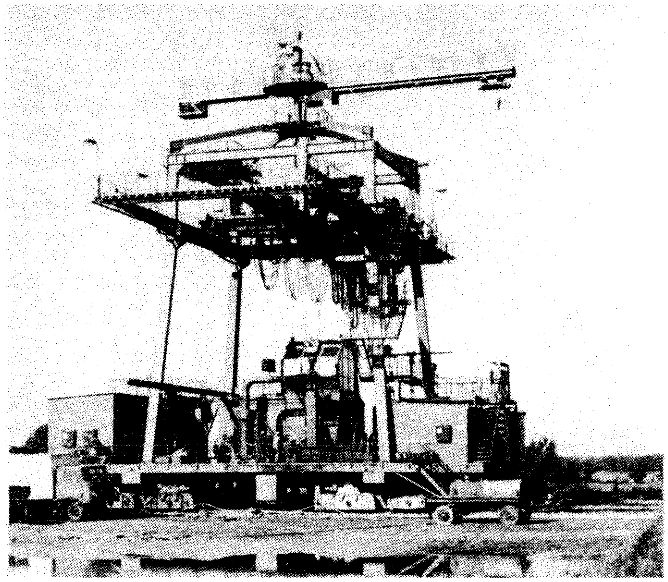


Figure 8 Milling Equipment Type SG 100

At present three such milling devices are working in tandem, each cutting a required length of trench for the sealing wall. The designed lengths of each of the sealing wall to be completed by each machine has been decided on the basis of the annual capacity of each machine. The single lengths will be seamlessly bound in one continuous wall preventing the ingress of water to the open-pit. Currently the machines are working down to depths of 83.5, 72.0 and 67 m respectively depending upon the depths of the impervious layers into which the diaphragm wall will be bound-in.

The actual cutting performance of a milling machine depends upon the type of strata present. For example , trenching operations in a strata contining 40 % sand and gravels, 40% clay, silt and lignite and 20 % boulder clay containing angular boulders up to 1500mm in length will involve some secondary blasting.

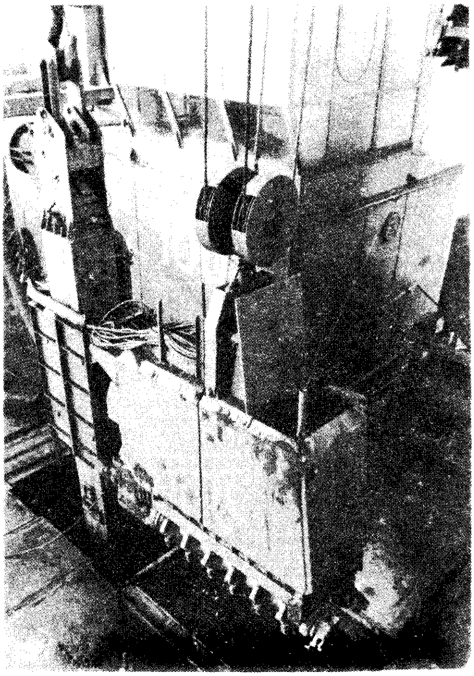


Figure 9. A View of the Twin Screw- Shaft Milling Device Type SG 100

The performance achieved in this strata by a SG 73 machine was 2.6 square metre per hour. The performance of a SG 100 machine in the same strata was 3.6 square metres per hour After secondary blasting has been carried out, the milling device runs through the chopped stones . The total amount of sealing wall finished at the Jaenschwalde open pit was 140,000 sq. m. per year. The effect of sealing wall construction is already evident at the two sides of the diaphragm wall, the water level at the pit side of the wall being 2m 1 wer than that in rise side of the aquifer.

Economic Considerations

The application of the sealing wall for ground water control is particularly suitable where the make of water is very high especially when mining is carried out in a highly saturated strata or an aquifer. A sealing wall is also an invaluable method of ground water control in situations where pumping may cause environmental pollution problems. The technique is capable of protecting excavations which come into close proximity with large rivers.

Generally, the diaphragm wall operations can greatly reduce the amount of water flowing through the sub-soil and also reduce the flow of the river water through the ground. Alternative techniques of ground water control by dewatering wells is very expensive in both initial cost of drilling and equipping the pumping well, power and maintenance cost of runnimg the pumps and refurbishing the well after its initial life of 12-15 years.

With regard to the diaphragm wall operations at the Jaenschwalde opencast mine, the following technical, economic and environmental advantages have been achieved:-

- o The application of the diaphragm wall technique has greatly reduced the requirement of pumping wells from three rows of wells to a single row. As a consequence the thickness of the barrier required at the mine boundary against the aquifer and the river Neisse is considerably reduced. Thus, the lignite reserves can be exploited to their maximum.

- o In comparison to the three rows of pumping wells, the estimated power consumption is reduced by 75%. Taking into account the projected working life, the savings of the power will be in order of 700 Millions Kilowatt- hours.

- o By using a single row of wells, it is estimated that the capital cost of drilling and installing 320 wells and their running costs will be saved.

- o As the life of the mine is about 25 years, and that of the dewatering wells between 12-15 years, it is estimated that the cost of refurbishing 320 dewatering wells will also be saved.

- o As the amount of water to be pumped out has been reduced, the size of water purification plant and related capital cost has been reduced.

- o The cone of depression due to the installation of a single row of the dewatering wells is considerably less than three rows of wells, thus creating less surface environmental problems.

With respect to the Berzdorf open cast mine diaphragm wall, an additional 70 million tonnes of lignite have been mined together with a savings in production costs of 24%. In addition the diaphragm wall technique has offered savings in capital costs and also surface environmental advantages similar to that realized at the Jaenschwalde lignite mine.