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Strategies for follow-up care and utilisation of closing and flooding in European hard coal mining areas

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ABSTRACT

The already implemented or near end of mining in the European hard coal mining areas will cause the rise of the water table which had been kept down for mining activities, and will finally re-establish the contact with the groundwater layers near the surface. This flood water causes contaminations of groundwater used for drinking water and therefore calls for immediate action, because of the in part high salinity and concentration of mobilisation products from the oxidised rocks. On the other hand the long-term process offers new options for discharge optimisation and utilisation.

The FLOMINET project carried out within the frame of the European RFCS program develops numerical models to forecast the impact of regional mine water rebound on mine, ground and surface water in interconnected underground hard coal mines. The research is also dedicated to the industrial utilisation of the rising mine water for renewable energy in form of electricity and geothermal heat. For this purpose numerical models have been enhanced in terms of density and temperature to become a practical planning tool for these activities. One additional application is the appraisal of gas reservoirs for methane gas extraction, the influence of the flooding process on such extraction, and the forecast of risks originating from mine gases dissolved in water after mine flooding.

1. Introduction: implications of closing and flooding in European hard coal mining areas

The development of coal consumption, worldwide exploration of coal deposits, transport conditions and world market prices have caused intensive effects on European hard coal mining areas in the last decades. Closure and flooding affected the mining areas in France, Belgium and England first but also Germany, where currently only 5 mines have remained active (Fischer and Hollmann, 2010). The last of these mines is supposed to be closed by 2018. The flooding process in the Ruhr area becomes evident by the recent water level distribution (Fig. 1). Even when taking the northern dip of the coal bearing strata into account, the 3 active mines appear as islands surrounded by abandoned mines with at least partial water accumulation.

Furthermore, large mining areas in Spain and even in Poland are equally affected by a closing process induced by the exploitation progress and shifting of mining activities.

In spite of site specific geological settings and varying mining technologies there are common processes accompanying the closure of mines established in Carboniferous strata in central Europe:

- The oxidation of pyrite in coal and host rock during active mining and ventilation forms a pool of soluble iron salts, which can be mobilised during flooding (Klinger, 2007). Subsequent mine water drainage is mostly affected by iron concentrations demanding water treatment before discharge. The flushing of these oxidation products can take decades (Eckart et al., 2010).
- The rising of the water table into the overlying strata may cause contact between mine water and the overlying groundwater aquifer, which was not possible under pre-mining conditions, (Eckart et al., 2006a, 2006b; Neumann and Terwelp, 2008). This may affect groundwater quality and, because of subsidence, also the groundwater level requiring intensive long term pumping activities (Shepley et al., 2008).
- Mine water flowing through deep mine voids shows high temperatures which in some cases reach more than 30 °C and might demand cooling before discharge. However, this also offers the chance for geothermal heat recovery when the mines are situated in a densely populated area and the pumping costs are not charged to the user

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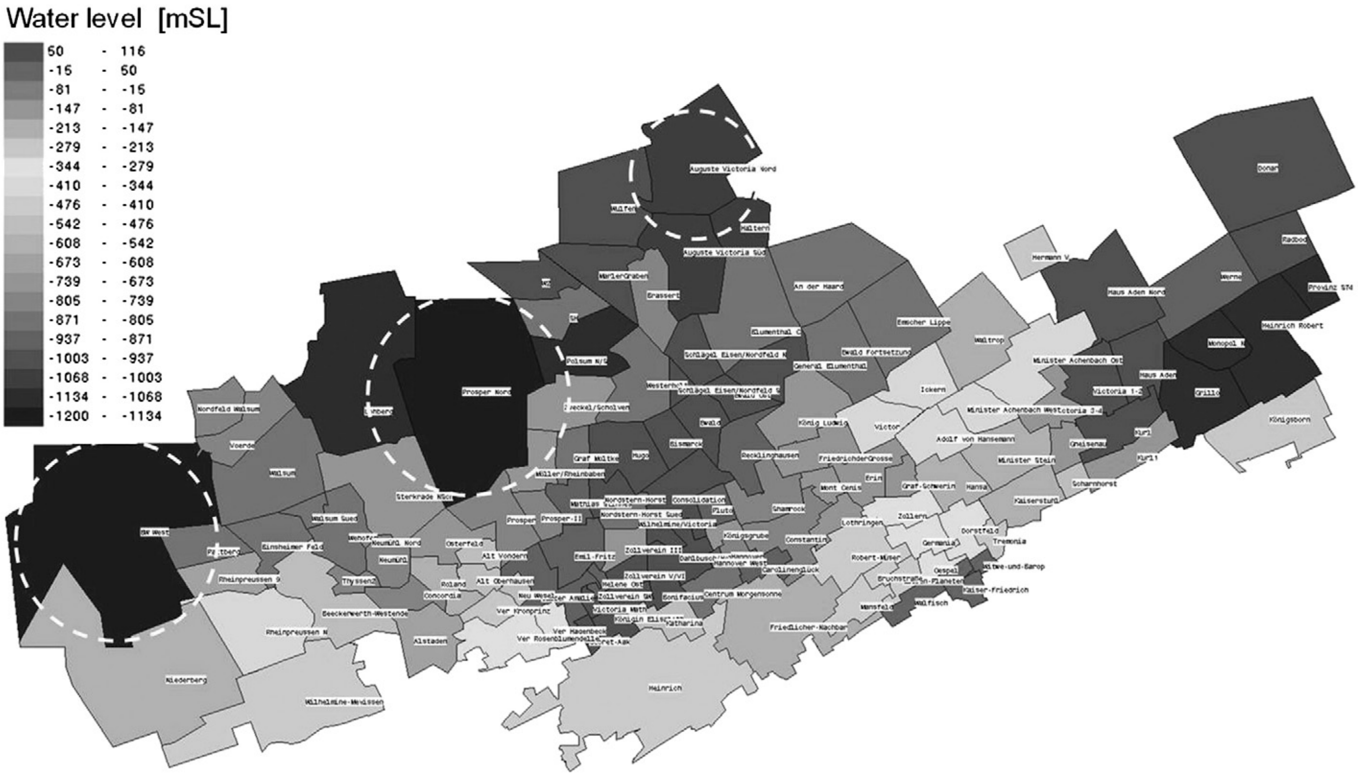

Fig. 1. Ruhr Area with the box distribution representing mines. Current water levels in the mines are indicated by shades of grey as result of recent Boxmodel calculations. The three still active mines are marked by the dashed white circles.

(Demollin-Schneiders et al., 2005). In addition, the geothermal potential accessed by the mine voids can be used by closed loop systems.

- The rocks caved by longwall mining are very sensitive to water and as they are constituted by an assemblage of blocks, the equilibrium found may be affected by the presence of water and a disturbance of the surface either by resettlement (Donnelly et al., 2007) or uplift (Sroka and Preusse, 2009). Additionally, volumetric changes due to swelling of coal and clays upon water saturation contribute to uplift processes.
- After mine closure the open voids are being filled with mine gas mainly consisting of methane, nitrogen and carbon dioxide. On the one hand this offers the opportunity for economically reliable gas extraction (Meiners and Kunz, 2006). On the other hand this gas reservoir may have contact with the surface and therefore induce gas migration with the danger of forming explosive gas mixtures. This danger is enhanced during the flooding when the rising water body pushes the mine gas to the surface (Rudolph et al., 2008).

These demands and potentials of the mine closure process show the requirement for the coordination of this process not only taking into account the economics of a short-term decommissioning but also the ecological and, the long-term economic situation. Flooding processes and their various impacts do not take place in a linear way. Fig. 2 illustrates the development of water levels in the Lorraine coal basin. Strategies for follow-up care and utilisation of mine closing and flooding require specially adopted model tools in order to provide forecasts of water table developments and environmental impacts on the surface.

2. The modelling tool Boxmodel

The Boxmodel program code forms an application orientated model tool for water flow, mass transport, heat transport and interaction in water–gas-systems (Eckart et al., 2004). In most cases mining fields with intensive mining activities resulting in a homogenously reacting hydraulic system are taken as boxes in the Boxmodel. These boxes are subdivided vertically into model slices and form the balance elements for all calculations (Kories and Eckart, 2006). The software allows for defining the structure of modelling cells and for installing many different kinds of connections among mining fields (Fig. 3).

The Boxmodel already serves as a prognostic tool for mine water issues in some important hard coal mining areas. Meanwhile considerable data are available to verify input parameters and assumptions. DMT has continued the development of the Boxmodel with the objective to improve the practicability and to standardise the methodology at various sites. In addition to the improvement of the already well established mine water flow models some important innovative programme codes have been implemented to model the following processes: coupled gas-water flow, energy production, high turbulent flow (storage), coupling of mine water with near surface ground water models and heat transport (Eckart et al., 2010).

The concept of the Boxmodel allows coupling of the mine model with groundwater aquifer models. Groundwater aquifer layers can be discretised by the Boxmodel in geometry and quality identically to the world wide most accepted groundwater models like MODFLOW (finite difference method) or FEFLOW (finite element models). There is also the option to couple existing groundwater models. Relatively small elements (cell sizes, edge length down to 200 m) are realizable even for large model areas like the entire Ruhr area or the Upper Silesian Coal Basin (USCB, Fig. 4). Routines for the large scale coupled ground water - mine water model allow quantification of the sinking rate from the ground water layer into the mines. Calibration of leakage effects in the groundwater aquifers overlying the mines will therefore differentiate between sinking into the dewatered mines and, for example, drinking water wells (Klinger et al., 2007). Lateral underground inflow/outflow through lateral model boundaries is also taken into account.

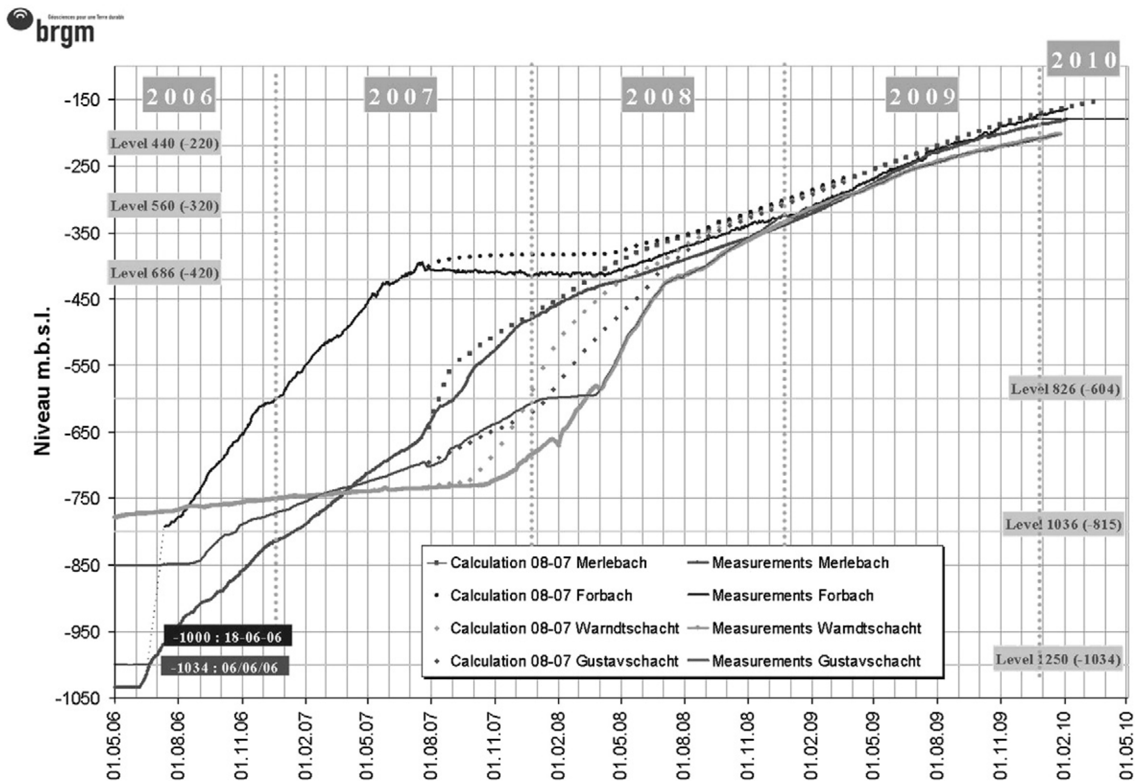

Fig. 2. Comparison of modelled rising waters (Boxmodel, dotted lines) with the measurements (data from BRGM) in the Lorraine Coal Basin (Babot et al., 2005; Eckart et al., 2010).

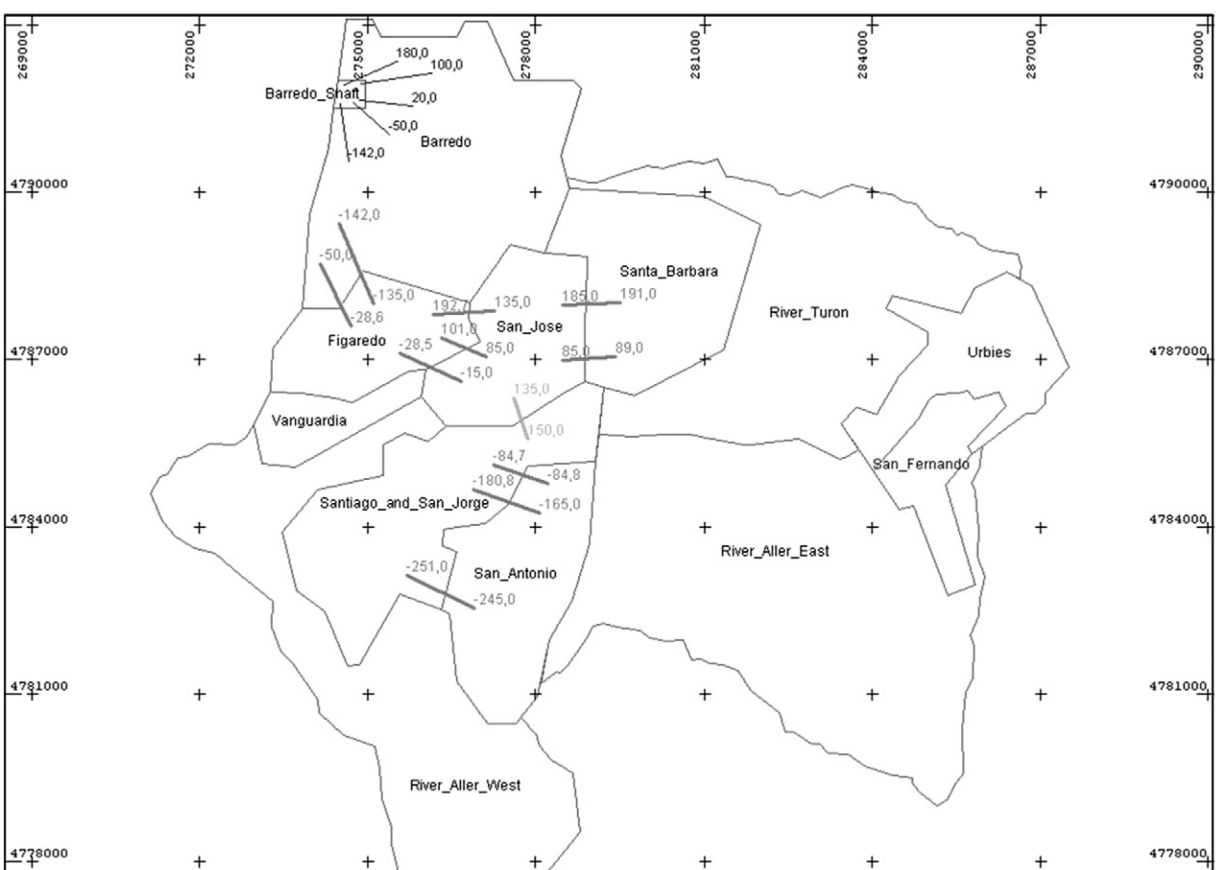

Fig. 3. Set of hydraulic connections in the Boxmodel for the Asturian Coal Basin.

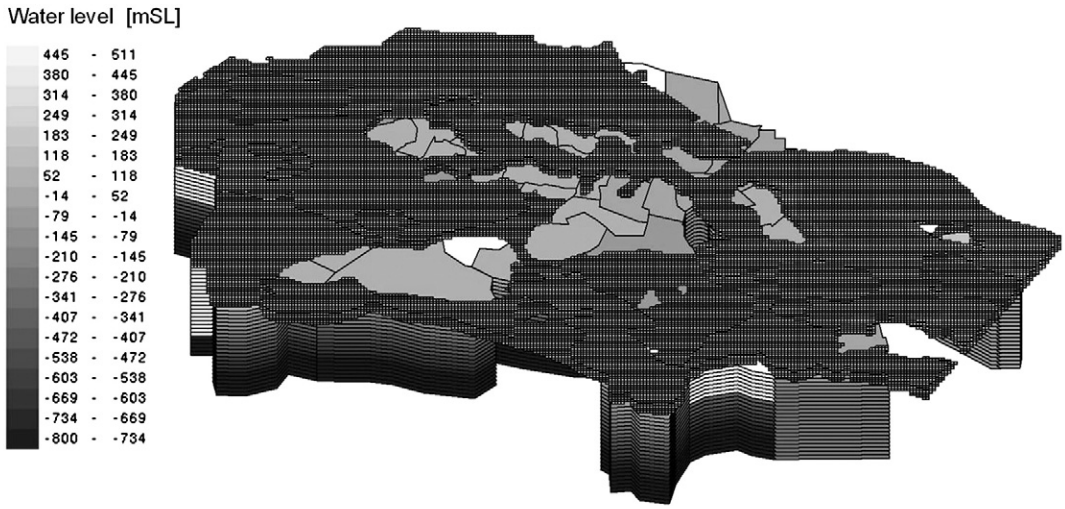

Fig. 4. Coupled model (mine–groundwater) in the Upper Silesian Coal Basin (Eckart et al., 2010).

Apart from the water balance the most relevant input data comprise the void volume which includes open drifts, workings (remaining voids after subsidence in the gob) and porosity of the rocks. The chemical composition of the water is required for the investigation of quality effects. The transport-tool of the Boxmodel is considering the transport phenomena convection, molecular diffusion, dispersion, geochemical solution-/precipitation processes, sorption / desorption as well as microbiological processes (Klinger et al., 2011). The Boxmodel is a multimigrant reactive mass-transport model. Up to now 30 inorganic (main cations, main anions, heavy metals) and 27 organic chemical components (PAH isomers, VOC, BTEX, Phenol etc.) are considered.

Detailed regional Boxmodels have been developed for the mining areas of the Ruhr Area (Fig. 1), Saar Area, Lorraine Coal Basin, Asturias (Figs. 3, 6, see Section 3), Upper Silesian Coal Basin (Fig. 4) and the Durham Coal field. A coupled interactive optimisation tool will allow scenario analysis regarding impacts on energy costs, environmental protection limits, payments and fees in regional mining network scales.

3. Geothermal heat recovery

3.1. State of the art: geothermal heat recovery from mine water

Due to drainage effects the concentrated mine water outflows have anomalous yield, specific chemical composition and higher temperature in comparison with natural springs. Furthermore, this temperature remains steady throughout the year (Sanner et al., 2003), making mine water suitable for geothermal energy recovery: all three elements of a low-grade geothermal system (heat source, water and permeability) are readily available (Ghomshei et al., 2003). Permeability is extensively present due to mine workings (in addition to fracture zones) while water is abundant below the water table.

The site-specific conditions of each coalfield or coal-mining area impact on the potential utilization of reservoirs for geothermal purposes (Malolepszy, 1998).

The temperature of water from the coal mining reservoirs in Europe is usually above 14 °C. Thus modern heat pumps using it as cold source are competitive, considering current prices of electricity and fuel. There has been worldwide research and applications of mine water as a source of low enthalpy geothermal energy: Poland (Malolepszy, 1998), UK (Burke, 2002; Sutton, 2002), Belgium (Van Tongeren and Dreesen, 2004), USA (Watzlaf and Ackman, 2006), Canada (Ghomshei et al., 2003; Lund, 2003; Raymond and Therrien, 2007), etc.

3.2. Technical feasibility of geothermal recovery in Asturias Carboniferous Basin: Geothermal potential assessment

The shaft of the Barredo Colliery has been selected for detailed geothermal study due to an average water temperature between 20 °C to 25 °C. This is the lowest discharge point of the regional mining infrastructure formed by Barredo, Figaredo, San José and Santa Barbara Collieries (Fig. 5). Thus pumping costs have been optimised.

Barredo Shaft is placed in the urban centre of the municipality of Mieres, at the right bank of Caudal river. In this town, the University of Oviedo was developing two new buildings, some 200 m from the shaft. Barredo Shaft is located at +220 m.a.s.l. The mine has five floors and the total depth of the shaft is 362 m (Fig. 5). As Barredo Shaft has a direct connection with Figaredo Colliery (see Fig. 3) all the water from the system could be drained by the former. The average water flow here reaches 4 Mm^3/year.

For the detailed studies being carried out in order to characterize the mine for geothermal energy production and to assess the evolution of its water quality, a Boxmodel of the whole Asturian Coal Basin has been generated. This allows for consideration of the hydraulic boundary conditions (Fig. 6).

Weekly temperature logging proved thermal stratification in the shaft with the above mentioned temperature maximum. In principle these results made the use of Barredo Mine water as a geothermal energy source feasible for heating and cooling buildings by means of commercial heat pumps. Such steady state results during the flooding are not necessarily significant for pumping activity, however, when cool water from the surface percolates into the mine. This is even more relevant for circulation systems via boreholes. The heating process depends on the flow paths, geothermal gradient, host rocks and flow rate. Numerical modelling has been used before evaluating the efficiency of proposed geothermal mine-water applications (Renz et al., 2009).

Boxmodel calculations taking into account the water infiltration in the large catchment area of the Asturian Coal Basin and the flow paths in the interconnected mine system to the discharging Barredo Shaft (see Fig. 3) proved the long-term stability of the temperatures evaluated after initial measurements in the flooding phase (Fig. 7).

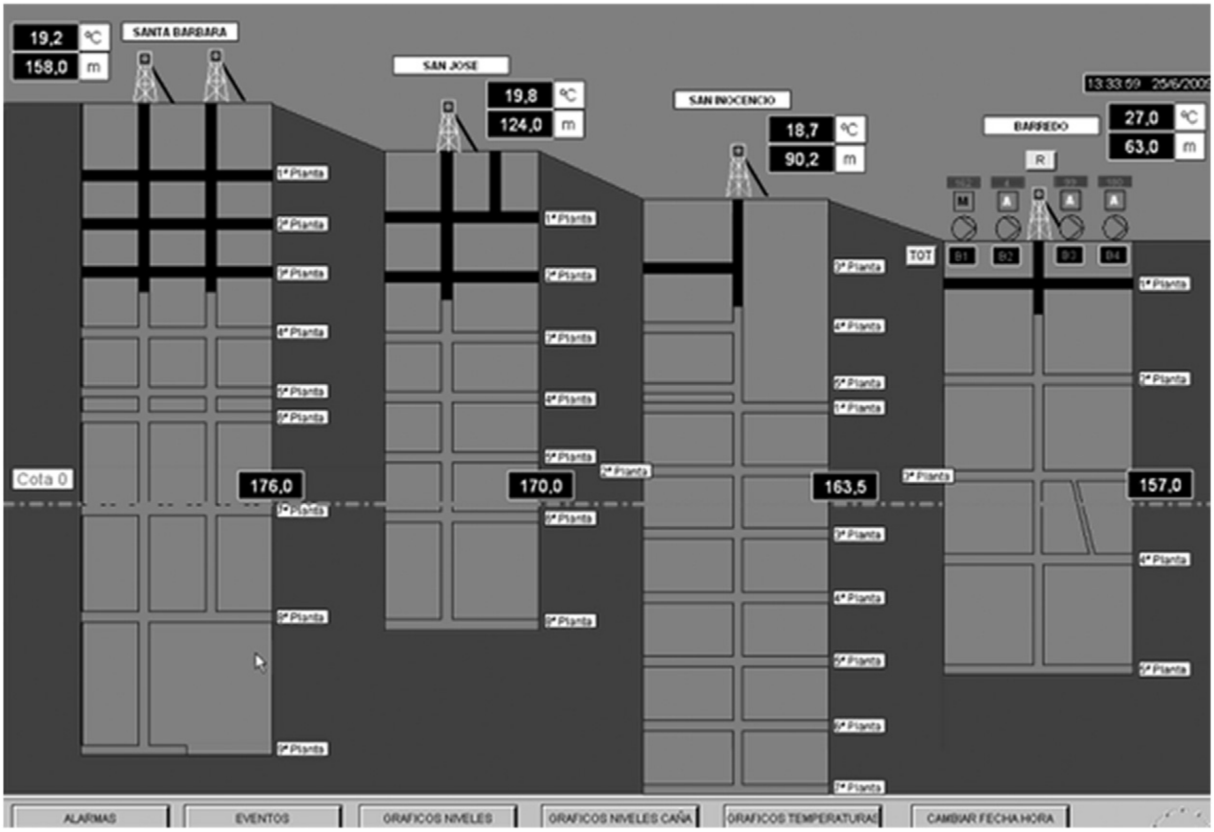

Fig. 5. Schematic cross section through the northern part of the flooded Asturias Coal Basin with monitoring system in the main shafts.

Calculations for another mine site in the Ruhr Area show decreasing mine water temperatures if the flow rate is too high, the flow path too short and cooling of the rocks occurs in the section of the mine where the water flows.(Fig. 8). A net of galleries between main inflow and decant point cause relatively short resident times of the water in the mine. The rock surface available for heat transfer is limited and flow rates show significant influence on the resulting temperature in the discharge.

The chemical characteristics of the water must be established in order to guarantee proper design and operational reliability. Chemical

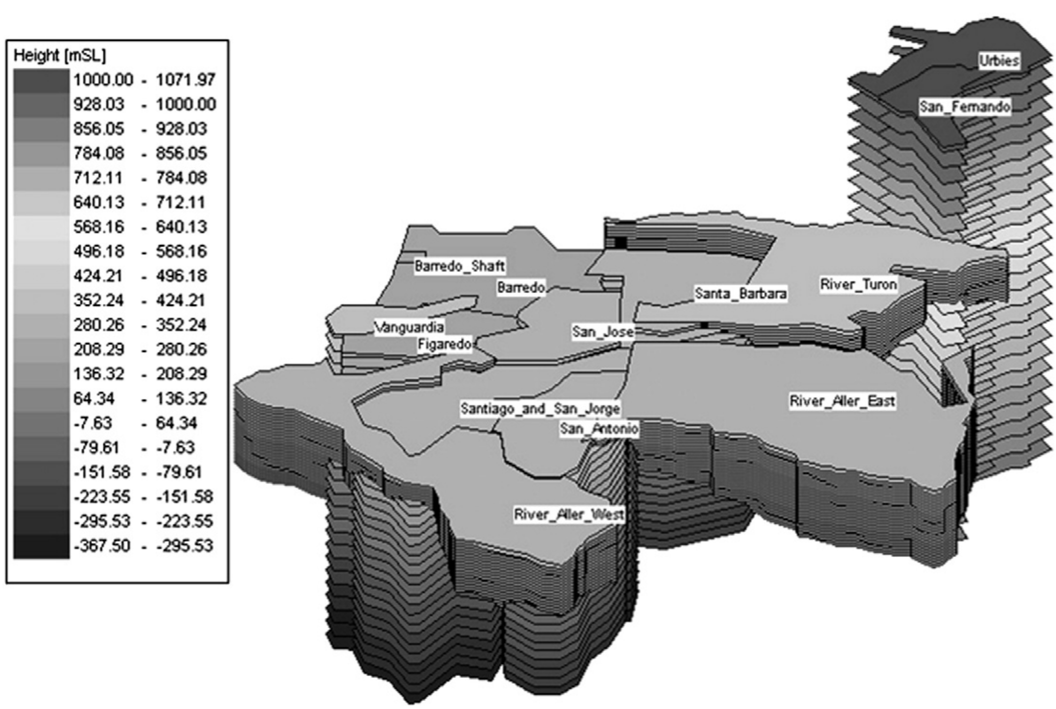

Fig. 6. Boxmodel for the Asturian Coal Basin.

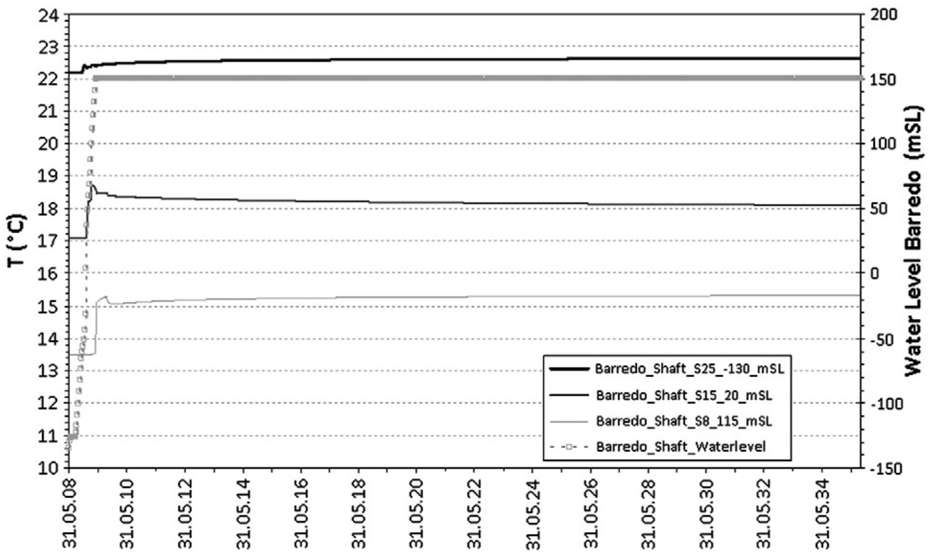

Fig. 7. Temperature development forecast (Boxmodel) for the mine water discharge at Barredo Shaft (Asturian Coal Basin) after mine flooding.

analyses of Asturian mine water proved there were no corrosion problems with the equipment. The mine water was mainly bicarbonate sodium water with pH above 7. However, the main water problem identified was its high hardness, exceeding in some cases 1000 mg/L. This follows that the main expected risk would be carbonate deposits that may harm the energy generation equipment. Results show that there will be some scaling problems related to this. Intermediate heat exchangers are necessary, instead of guiding the mine water directly into the heat pump. To assess the energy potential of Barredo-Figaredo Unit, an average water flow of 4 Mm^3 per year has been considered. Although re-injection of the water has not been considered so far there is an option to do so in the future. Therefore, the thermal potential in the cold source can be calculated as the product of the thermal gap, the water flow, the density of the water and the specific heat:

$$Pf = (dT \cdot V \cdot Ce \cdot \rho) \cdot (Wth) \tag{1}$$

where:

- T Thermal gap, 5 °C (on conventional heat pumps)
- V Water flow per year (4 Mm^3/year)
- Ce Water specific heat (4186.8 J/kg °C)
- ρ Density

These data allowed estimation of the thermal potential of the mine water as 2.65 MWth at the cold source. The thermal potential of the hot focus can be calculated as:

$$Pc = Pf + W_e \tag{2}$$

Where W_e is the energy consumed by the heat pump compressor ($W_e \approx 0.66$ MW). The water temperature is around 23 °C and it is intended to produce energy at 40 °C, thus a standard Coefficient of Performance (COP) can reach 5 (Rodrıguez and Dıaz, 2009).

$$COP = \frac{P_c}{W_e} = \frac{P_f + W_e}{W_e} = 1 + \frac{P_f}{W_e} > 5 \tag{3}$$

The energy supplied to the heat pump at the compressor will be around 0.66 MW, reaching a thermal potential of the hot focus of 3.31 MW of heating-cooling power.

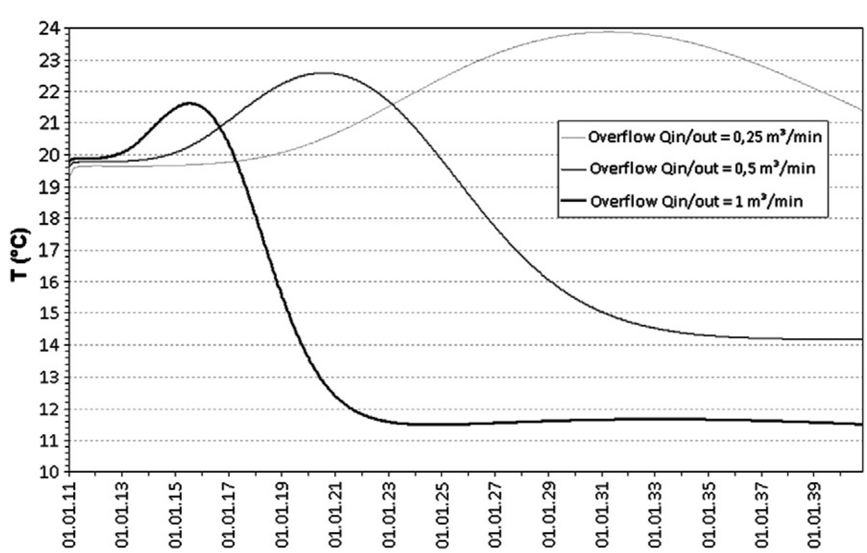

Fig. 8. Temperature development prognosis (Boxmodel) for a mine water circulation system in the Ruhr area with different flow rates.

3.3. Barredo Geothermal pilot project implementation

Taking into account all that data, a new geothermal pilot project has been realized in Asturias, Spain, with heating/cooling systems of two buildings of the University of Oviedo near the mine water discharge at Barredo Shaft. These promising results for the characterization of the geothermal reservoir and the closeness of two new buildings under construction to Barredo Shaft allowed implementation of a pilot project for geothermal energy supply to the new buildings at Barredo Campus (both of them owned by University of Oviedo) by use of mine water. These two new buildings (a Research Centre and a Hall of Residence) were in their early stages of construction when it was decided to implement the project, but it was necessary to implement some changes in order to provide mine water as an alternative thermal energy source.

The installations required to provide geothermal energy to the buildings can be divided into three main parts:

- Pumping System at Barredo Shaft, which provides the required water flow for the geothermal system.
- Water distribution system to the buildings.
- Heating and cooling generation systems (heat pumps and the auxiliary equipment required for operation).

Due to the simultaneous demand of heat and cooling at the Research Centre building, a compensated generation system is planned (Fig. 9), consisting of two chillers RTWB 210 (heating power of 362 kW each unit). Both chillers produce hot water at 50 °C that returns at 45 °C after being used on the heat circuit and simultaneous cold water on the cold focus at 7 °C. When the water comes back from the cold circuit of the building it returns at 12 °C. Thus the heat pump can work steadily with a thermal gap of 5 °C on each focus. Should the thermal loads become unbalanced, mine water acts as a balancing fluid. When cold requirement exceeds the heat requirements the mine water decreases the temperature of the return water of the heating circuit through a plate heat exchanger (UFP 102/55). Furthermore, in winter time the mine water is used to dissipate the excess cold produced by the chillers ensuring that they can operate with an appropriate thermal gap.

As for the Hall of Residence, the generation scheme is simple because cooling is not required. A heat pump RTWB 207 produces hot water at 35 °C with a runback temperature of 30 °C.

Even considering the pumping costs, heat pump technologies are still highly competitive compared to other conventional systems, like gas-oil and natural gas. In addition, it is expected that this competitiveness will improve according to the market forecasts for natural gas prices. The use of this heat source also reduces CO_2 emissions. Gas-oil or natural gas systems would produce CO_2 emissions 55% respectively 18% higher compared to those of the heat pump technologies. Therefore it can be concluded that geothermal use of mine water is an appropriate action towards greenhouse gases mitigation.

4. Gas mobilisation, migration and extraction

Mine gas consisting of Methane, Oxygen, N_2 and CO_2 is the natural attendant of coal and coal mining (Doyle, 2001). Closure of hard coal mines has therefore to consider interactions between water and gas in a hydro-geological context of mines during and after flooding (Meiners and Kunz, 2006, Meiners et al., 2002). The corresponding processes can be described in two different approaches at two different scales.

On the one hand interactions between water level rise and gas emissions during flooding can be described with the Boxmodel at a large scale (mine network, coal basin). The concept of the Boxmodel-approach considers one gas phase for describing the gas-flow (mix of all gases) and a multi-component concept for the mass transport model (components of the gas phase). A minimum of two components is considered: the concentration of methane and the sum of the rest (N_2, CO_2, H_2S). Because of the large scale of the Boxmodel the gas dissolved in water is not considered. The flooding water table forms a sharp boundary to the mine not yet flooded, but still filled with gas. After flooding of coal seams the methane source is blocked.

On the other hand, at a smaller scale, the gas transport as dissolved phase emanating to the surface from unexploited coal after flooding was studied. This work was performed with the help of CASPER device (laboratory tool developed for this study) and HYTEC code (developed by the Reactive Hydrodynamic group of the Department of Geosciences of Mines ParisTech).

Both approaches will help to better evaluate the risk for populations living on the surface (Edelhoff-Dauben, 2001) and to evaluate the feasibility of using CH_4 for recovering energy. In comparison to the Boxmodel the HYTEC-concept has a much higher resolution allowing for

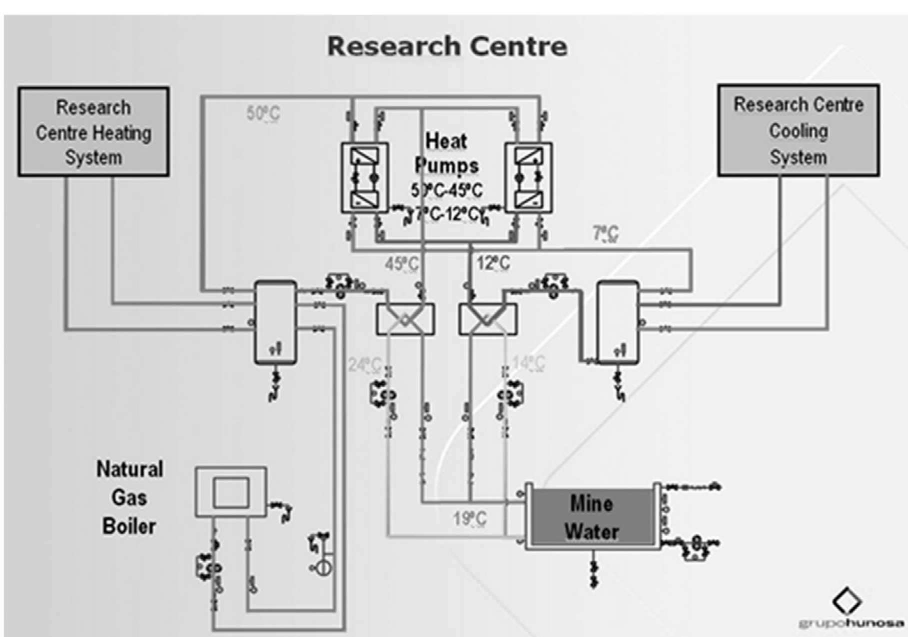

Fig. 9. Generation equipment for the Research Centre at Mieres, Asturias.

description of the multiphase-flow (pore water–gas–capillary pressure). In the current configuration one chemical component (CH_4) is considered for the mass transport tool. In contrast to the Boxmodel HYTEC is also considering CH_4 as a dissolved phase in water.

4.1. Gas extraction during mine voids flooding

The source-term of gas generation depends on the real gas content (given by the residual gas content in coal (kg/m^3-coal) and the mass of residual coal (t) per mine field) and the permeability from the point of gas sorption to the open drift system. In the so called passive period methane flows from the seam to the drift system without a suction pressure only on basis of the higher sorption pressure in the seam. This process is the reason for uncontrolled methane emissions from closed mines (Hollmann, 2001; Pokryszka et al., 2005). Active gas pumping results in pressure reduction in the mine voids and enhanced desorption and migration of methane to the pumping station (Durucan et al., 2004). A typical feature of gas production in active mines is a much higher gas production rate than under post mining conditions, caused primarily by movement of geological formations (subsidence after exploitation of the coal) and secondly by artificial measures to prevent gas flow into the drifts (gas suction from seems over special drill holes).

Active gas extraction therefore provides the possibility of post mining hydrocarbon use with additional reduction of uncontrolled gas release into the environment. It is limited, however, by the flooding process causing gas production to cease (Meiners and Kunz, 2006). On the other hand diffuse gas flux to the surface is enhanced during the flooding and affects urban hard coal mining areas in the post mining stage.

The dependency of gas pressure and flow on gas pumping activities and the development of methane concentration in the Lorraine Coal Basin are shown in Figs. 10 and 11 on the basis of measuring data (BRGM) and Boxmodel results. The following input data have been considered for calibration of the gas model tool for the regional model:

- Points of gas pumping (x,y,z)
- Pressure development versus time p(t)
- Volume of gas pumped
- Concentration development of methane at the pumping points
- Source term description: residual gas content in coal [kg/m^3-coal]
- Mass of residual coal (t) per mine field.

The source-term of gas production (mainly the coal seams) is linked to the rising water table. Successive flooding of seams causes cut-off of the specific gas production in this source. As a result the total gas production rate is decreasing with rising water table.

The considered differential equation for the transport of the gas phase is:

$$d(\theta\rho)/dt = d(\rho u)/ds + \rho q \quad (4)$$

with

θ	– Porosity	[−]
ρ	– Density of gas phase	[kg/m3]
u	– Darcy-velocity of gas phase	[m/s]
ρ q	– Sink/source term of gas phase	[kg/s/m^3]
p_g	– Pressure of phase	[kg/(s^{2}m)]

On the basis of the mass-flow formula of the gas phase the transport of two components (1: methane, 2: anonym gas for dilution (CO_2, O_2, N_2, ...)) must be described (coupled one phase and two components flow). For this reason the formula of mass flow of the gas phase has to be extended by the concentration to:

$$d(c\rho)/dt = d(c\rho u)/ds \quad (5)$$

with

c	– Concentration of a component	[1] or [100%]

For the description of the flow field during the flooding the Boxmodel considers 3 compartments: (1) the open drift system, (2) the so called stagnant phase and (3) the sorbed methane phase at the coal. The mass transport out of the stagnant phase is comparable with matrix diffusion.

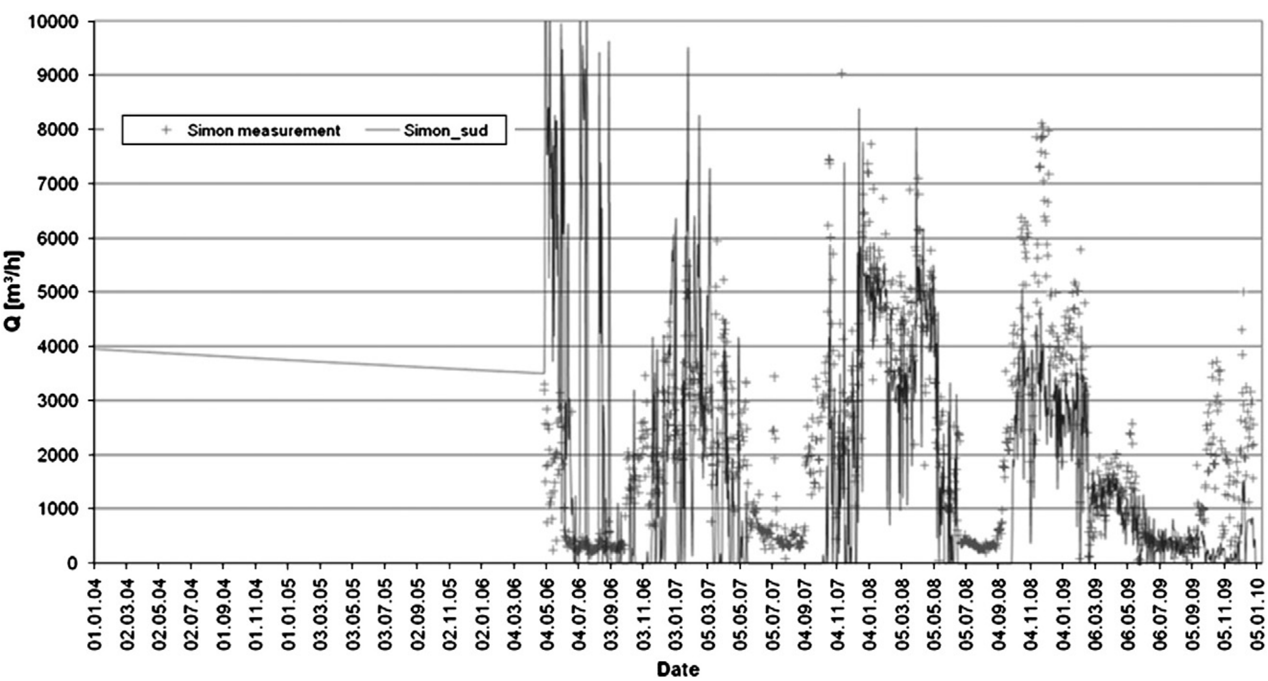

Fig. 10. Calculated and measured gas flow (influenced by flooding) in the Lorraine Coal Basin, Simon shaft.

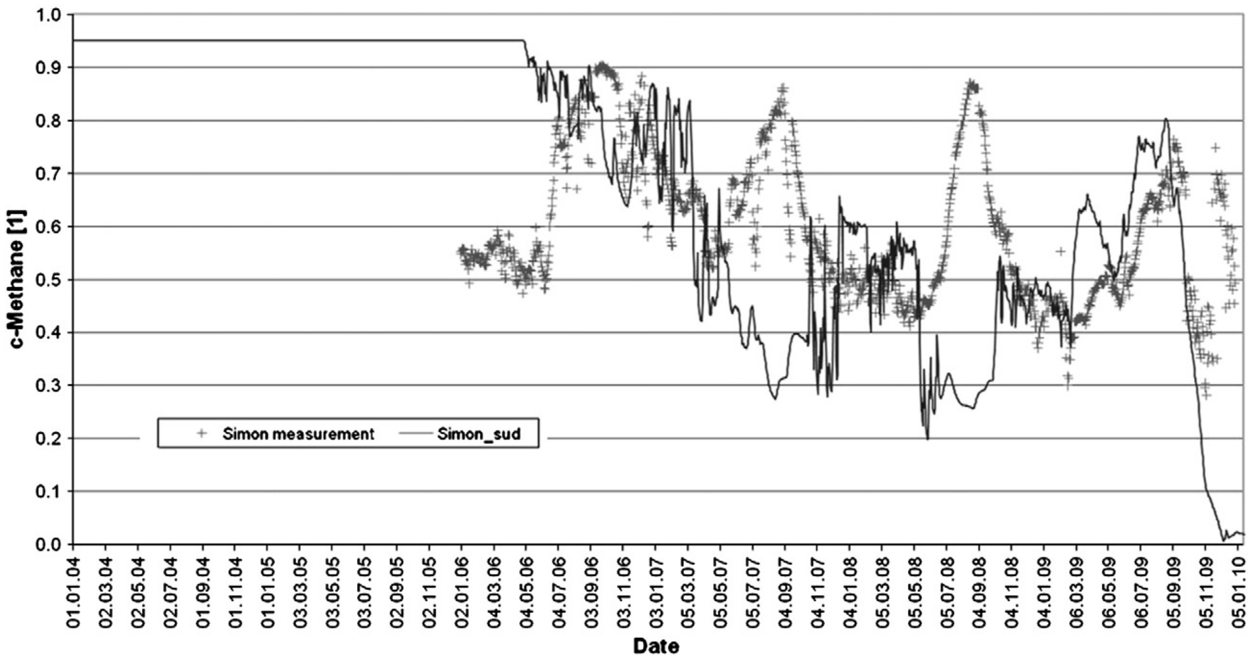

Fig. 11. Calculated and measured development of the methane fraction in the gas phase in the Lorraine Coal Basin, Simon shaft.

The stagnant phase comprises the old workings (gob) with a lower permeability compared with the open drift system. The desorbed gas must flow via the stagnant phase to the drift system and subsequently through the drift system to the pumping system. The compartments are numerically linked by a kinetic transfer equation. To realize the described concept the model needs the following variables: pressure in 3 compartments (drifts, stagnant phase, sorbed phase) and in minimum 2 concentrations in each compartment (6 concentrations).

4.2. Effect of flooding on gas emission at short time scale

In situ gas monitoring performed in old shafts during the flooding of the La Houve Basin confirmed a first massive gas release just after the beginning of the water level rise. This first period of gas flow is followed by a constant decrease until the end of the flooding. At this stage and during water level increase, gas is expelled by piston effect due to the void volume reduction.

However, there is a positive effect on gas emissions coming from old mines just after flooding. After flooding of the last mine voids gas flow out of wells reached concentration levels (CO_2, CH_4 and O_2) comparable to atmospheric gas concentrations. Therefore, the evolution of void volume during flooding is the main parameter which controls mine gas outflow.

4.3. Effect of flooding on gas emission at long time scale

Nevertheless, field operators found CH_4 concentrations in shafts under concrete caps in Lorrain Basin during recent field observations and measurements. On the basis of these studies it can be assumed that gas emissions occur connected with mine water flow after mine

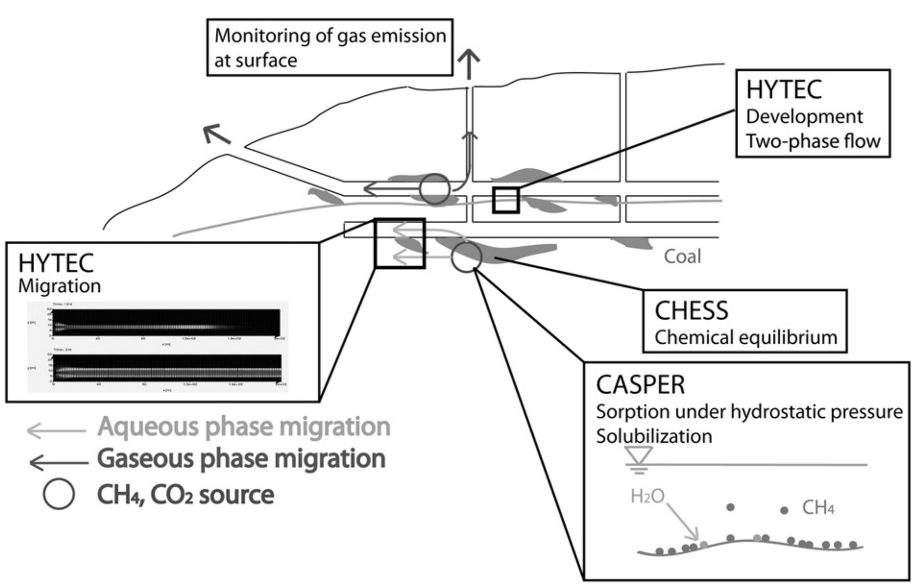

Fig. 12. Conceptual sketch presenting the different approaches for specification of post flooding gas emissions.

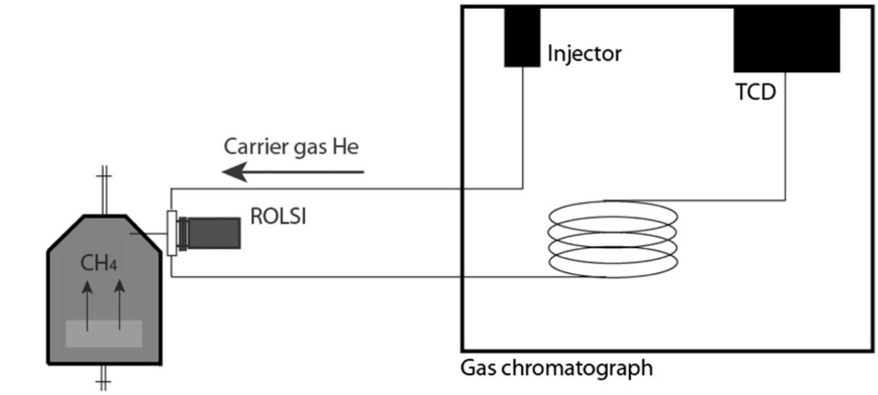

Fig. 13. Scheme of the sampling/analysis system of CASPER (Le Gal et al., 2010).

flooding. Fig. 12 shows the emission paths and the research methods used for studying the physical and chemical parameters regulating gas flow from the mine to the surface and their relative influence. Further studies have been concentrated on CH_4 migration to test the long term flooding effect on gas migration.

Methane adsorption and methane release under variable hydrostatic pressure have been studied with an experimental device. For that INERIS has developed CASPER (CApacité de Sorption à hautes Pressions lors de l'Ennoyage des Roches / sorption capacity at high pressures during rock flooding) (Fig. 13). The main objective is the determination of methane transfer (desorption rate) from coal to water at different hydrostatic pressures (Le Gal et al., 2010). The knowledge of this parameter is essential to assess the possibility of gas migration as dissolved phase from old coal mines toward the surface after the flooding process (Busch et al., 2006; Crosdale et al., 2008).

The experimental protocol is the following. Once the CH_4-saturated coal sample is flooded, water droplets are sampled, vaporized and flushed by the carrier gas into the gas chromatograph (Fig. 13). This device allowed measurement of dissolved CH_4 in water and the kinetics of CH_4 desorption at given pressures (Duan and Mao, 2006). These data form the basis for subsequent modelling works. The results obtained show that CH_4 transfer from coal into solution is more than four times lower in experimental conditions than the theoretical solubility of methane in mine flooding water, relating to findings in Lorrain Coal Basin.

The reactive transport code HYTEC (developed by the Reactive Hydrodynamic group of the Department of Geosciences of Mines Paris-Tech) simulates reactive migration of aqueous species (van der Lee et al., 2003). It has recently been improved to take into account gas migration as gas phase or under dissolved phase. Transport parameters, porosity, saturation of the media, permeability, diffusivity and dispersion are considered. The methane sorption phenomenon on coal has been defined corresponding to the first results of laboratory experiments realized with CASPER and considering the rate of released CH_4 at a given temperature and pressure.

At first different model configurations allowing characterisation of the impact of mine structures on CH_4 migration have been tested. This modelling serves code calibration. At this stage,, the target is not to simulate the migration of methane under dissolved phase at the scale of the mining basin, but to test the model capacity to reproduce this kind of gas transport in an heterogeneous media. Fig. 14 demonstrates the effect of a fracture linked to a gallery: instead of diffusing equally in the porous media, the plume circulates at first in the fracture and then penetrates the medium.

It could be shown that in case of coal containing methane, this gas can be dissolved and transferred as $CH_4(aq)$ through existing galleries or fractures. This result demonstrates that a rise of gas to the surface via water transport is generally possible. For super-saturated mine water, degassing on the surface can be envisaged.

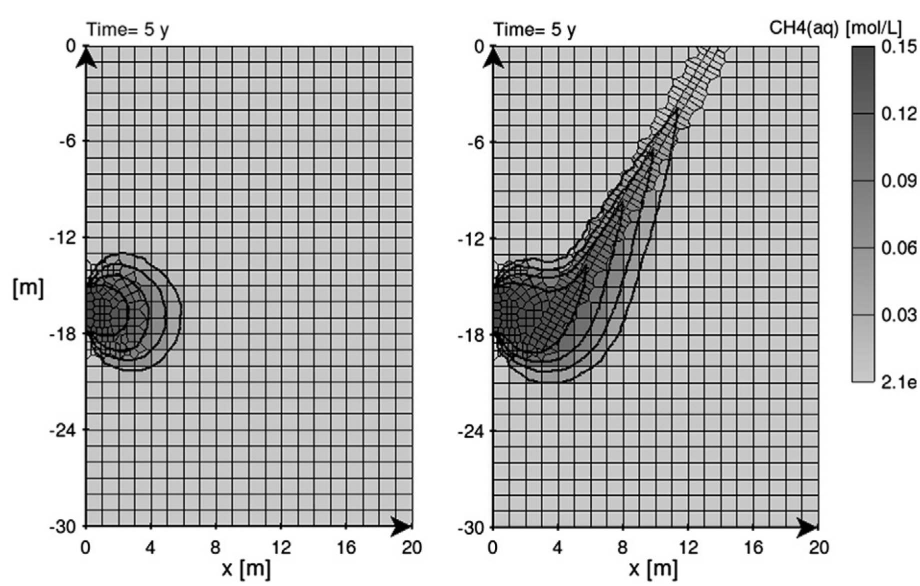

Fig. 14. Migration of aqueous CH_4 through a fracture connected to a gallery at 2 years and 10 years, with a head gradient equal to 0.01. The migration is indicated by the bright shades (After Le Gal et al., 2010).

With the current results it is not yet possible to accurately quantify gas emitted on the scale of a mining basin. More laboratory experiments and improvement of the modelling tools have to be conducted. This is necessary for the quantification of the amount of gas that can be dissolved in the mine water at reservoir conditions, and to evaluate the probability of degassing.

5. Conclusion

In spite of obvious demand for further enhancements the model approaches seem promising for integration of post mining demands into recent strategies for mining management and closedown. In contrast to new mining projects the consequences of the mining period for the environment in the long term have not been subject to initial planning, and the recent mining structure is often the result of a long and changeful history. Appropriate model tools are available to assess the complex site data in order to develop the long term concepts important for the overall cost effectiveness now, when mining is still active and required infrastructural procedures can be implemented.

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