Modeling of gas extraction from closed coal mines

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ABSTRACT: The closed coal mines carry on releasing firedamp. In some cases, the quantity of gas released is not negligible and it can induce an overpressure in old works. A means to avoid hazards related to these gas emissions at the surface is to put in drainage installations and to keep the pressure of the underground reservoir under the atmospheric **one.** This practice has been used in several mines in France like in the Lorraine basin. A mathematical model has been developed by INERIS in order to improve operation of such installations. This model needs to determine 4 main parameters of reservoir. After its calibration, it is possible to forecast daily variations of pressure and methane content in drained gas as a function of daily extracted gas flow rate. Validations were made for several years. This model is able to evaluate firedamp quantity which may be extracted for a given period and to **characterize** the extraction conditions allowing an optimal production and its durability.

1 INTRODUCTION

One way to prevent efficiently firedamp migration from **closed** mines towards the surface is to extract gas and keep the old mining works in depression. This partial depression of underground reservoir can be obtained by means of global industrial gas drainage from the surface.

Some installations of this kind exist in France in Nord-Pas-de-Calais and Lorraine coal basins. One of those operates in Saint-Charles closed mine located in the Lorraine basin, in the East of France (figure 1). This site was closed down in June 1991 mainly with closing of two shafts (Saint-Charles 1 and 3). The gas extraction installation is connected to the reservoir using pipelines through the old shaft Saint Charles 2 closed by a concrete **dam.** This site is **isolated** from nearby workings. It is still in exploitation with a mean methane volume of $10 \cdot 10^6$ m^3 extracted each year. Each day, the gas exploitation data are registered:

- standard gas rate flow;
- methane content;
- reservoir pressure (measured in shaft head);
- atmospheric pressure.

This global firedamp drainage needs a good operationplanning.
Indeed, after a temporary or permanent stoppage of the gas **drainage,** the reservoir pressure increases up to an equilibrium pressure greater than the atmospheric pressure. As a result, gas can escape uncontrollably to the surface. The analytical modeling can help in an optimal and safe management of industrial gas drainage from the surface.

In this **aim,** a specific mathematical model has been developed by INERIS in France able to forecast reservoirs behavior in a function of operating parameters **(Couillet** et **al.** 1998).

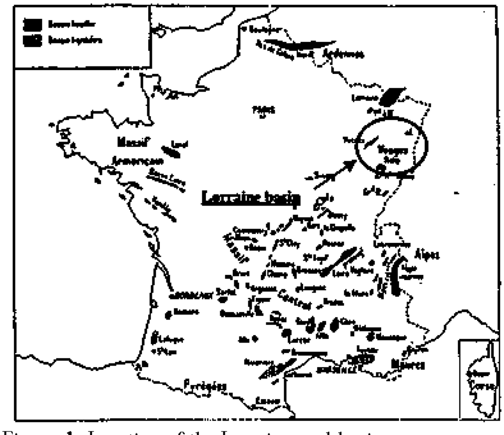


Figure **1.** Location of the Lorraine coal basin

2 PRESENTATION OF THE MODEL

2.1 Principles ofthe model

The old mine workings with the entire strata volume destabilized by exploitation are assumed to represent a firedamp reservoir. This reservoir will be of given volume, VR, but defined limits or strata will not materialize it. Usually, the volume V_R corresponds to the residual volume of exploitation cavities and spaces due to neighbor strata cracking and porosity.

The firedamp is stored in free form in this volume, and principally under an adsorbed form on the coal seems.

This reservoir will be connected to drainage surface installations through old shafts or drainage boreholes. In such installations, the reservoir pressure value, the quantity of the captured gas and its methane content are usually registered.

The pressure of this volume will vary with the outgoing flow rate of mine drainage and the "produced" gas flow rate.

The "produced" gas flow rate is the contribution of two phenomenon which are:

- incoming flow of firedamp desorption, QD
- incoming flow of atmospheric air, QA

QD is regarded during a rather short period of time as a decreasing linear function according to the pressure within the reservoir. By introducing the parameters a and P, QD is equal to:

$$Q_D = \alpha \, \Delta P + \beta \quad (1)$$

Q_A is related to the depression of the reservoir relatively to the atmosphere, noted AP, by the following law:

$$\Delta P = R Q_A^{\chi} \quad (2)$$

with R, equivalent **aeraulic** resistance of reservoir cover strata and
χ, coefficient; value of this coefficient is 2 for a turbulent flow and 1 for a laminar flow.

Assumption is made on the flow laminar nature (Darcy flow). By introducing parameter γ, it is then possible to write:

$$Q_A = \gamma \, \Delta P \quad (3)$$

So, the total incoming flow of gas is the sum of the two flows and is expressed as:

$$Q_P = Q_A + Q_D = (\alpha + \gamma) \, \Delta P + \beta \quad (4)$$

with:

- a, the firedamp desorption capacity depending on the reservoir pressure
- (3, the firedamp desorption capacity independent of the reservoir pressure
- γ, the atmospheric air inflow capacity of the reservoir.

2.2 *Modeling*

2.2.1 Calculation ofthe pressure in the reservoir

The calculation of the pressure variations is possible with the knowledge of:

- the drainage mine gas quantities (measured data)
- the incoming gas quantities (formula 1 and 3)
- the evaluation of the reservoir volume, V_R

This assessment reiterated with a given time step permits a dynamic modeling of the pressure evolution within the reservoir.

2.2.2 *Calculation of methane content in drained gas*

The same method is used to model methane content of the drained gas. The methane content in the drained firedamp is assumed to be equal to real seam value (usually 100 % on the studied coal deposit conditions). Then, a mass balance is made between firedamp desorption and drained methane quantities (based on measured data).

2.3 Calibration and initialization

In a first step of modeling, the model needs to be calibrated. These validation consists in the determination of 4 parameters of the reservoir: α, β, Y and VR (see §2.1), using the past experimental data.

To ensure this validation, the calculated and the measured parameters (pressure of the reservoir and methane content in drained gas) are compared.

The parameters are considered as satisfying when the absolute average error between measured and forecast data is below to 10%. However, attention must be paid on the type of measured data used for calibration. For example, periods of drainage stoppage are not appropriate to validation of methane content calculation. Indeed, in this situation the methane content measured in the connection devices between the reservoir and pumping station may not be as representative of real reservoir methane content as during an extraction period.

The comparison of the data can require another calibration of the parameters and a new initialization of the calculations. The model parameters have to be adjusted until the less discrepancies are obtained between the measured and calculated results.

2.4 *Kind ofmodeling*

The knowledge of the reservoir's behavior and particularly its capacities of methane production is of prime interest for the operator. This knowledge can be improved using the model by simulation of various operation situations, for example:

- reservoir response to gas extraction: this type of information can be useful for the operators to understand the long-term behavior of the reservoir at a given and periodic rate of exploitation. It will be useful to determine the production capabilities of a reservoir;
- reservoir pressure evolution after temporary or permanent gas drainage stoppage: the application of the model is expected to forecast the time necessary for an increase of pressure within the reservoir up to the atmospheric pressure. This information is essential for safe management of firedamp **reservoirs,** since it gives the period of drainage cutoff collection not to be exceeded.

3 EXAMPLES OF MODEL APPLICATION

In the past, the model has been validated and used with a good result on some closed mines drained reservoirs in the French coal basins **(Couillet** et al. 1998).

In this paper, some examples of model application on the case of Saint-Charles reservoir in Lorraine coal basin (see § 1.2) are presented.

3.1 Calibration

For this reservoir, the first calibrations of the model were operated in the previous study using the operating data of 1995 and 1996 (Couillet, 1998). Table 1 shows the value of the parameters determined for that period.

Parameters	1995
Reservoir volume, V_R (m^3)	**12.10^6**
a [m^3/day Pa]	2.2
Y [m^3/day Pa]	3.4
3 [m^3/day]	**20 000**

Table 1. Saint-Charles reservoir. Parameters determined for year 1995.

A detailed analysis (CECA 2003) using the new registered data from the period 1997-2002 has shown that the characteristic of the reservoir did not change a lot even after 7 years. It must be specified that in this area, water rising has not yet started, so reservoir volume is unchanged. Methane **desorption** capacity and air inlet characteristics did not change really too.

The preliminary modeling of reservoir pressure and methane content in drained gas, using the reservoir parameters from 1995, has shown very limited discrepancies between calculated and measured values.

Thus, the calibration of the model and new evaluation of reservoir parameters was not necessary to obtain a good forecast of the pressure and methane content

So, parameters determined in 1995 were used to forecast the reservoir behavior in the future.

3.2 Modeling of the behavior in the gas extracting phase

The simulated gas production program predicted by operator are: collected gas flow of $1.1 \cdot 10^5$ m^3/day during operating periods (9 months) followed by a cessation of drainage for three months.

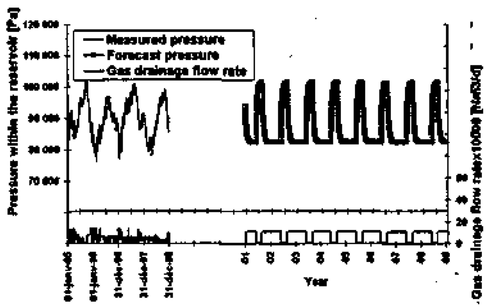
Two configurations were considered:

- an optimistic forecast
- a pessimistic forecast

The optimistic forecast consists on taking exactly all parameters as defined in table **1.** The pessimistic forecast consists on taking all parameters as defined in table **1,** except P (firedamp flow rate). It is in fact possible that desorption capacity of reservoir decrease in the future. Following this hypothesis, the desorption flow rate is taken equal to half the value defined in table 1 (P = 10 000 m^3/day).

Methane content and pressure were modeled. Only the results relative to the optimistic forecast are presented on figures 2 and 3.

Figure 2. Modeling in the pumping phase - Reservoir



Saint-Charles - Pressure evolution

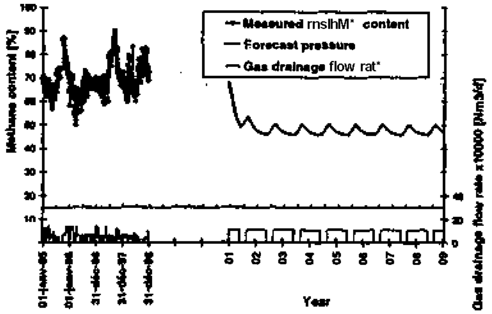


Figure 3. Modeling in the pumping phase - Reservoir Saint-Charles - Methane content evolution

It can be seen that reservoir pressure reduces quickly after drainage beginning. Methane content drops quickly and remains below 50% even in the second year of operation. This level of methane content in collected gas is just sufficient for drainage continuation, but operating margins are low. In the case of the pessimistic forecast, methane content is much lower. It quickly drops below the limit of 30%. In this situation, continuous exploitation of the reservoir is not possible.

These simulations show that methane content in the captured gas can drop until it is too low to operate the system in safe conditions. This predicted rate of exploitation will not necessarily be reliable in the long term.

Other simulations have to be carried out so that the capacities of the reservoir can be used satisfactorily, with reduction in the collection flow or prolonging stoppage periods.

3.2.1 Study ofthe cessation ofgas drainage

Pressure variation after the cessation of gas drainage was modeled taking the initial pressure equal to the pressure that occurs in the reservoir during a stable pumping period. The simulations carried out indicate (Fig. 4) that reservoir pressure can increase rapidly after firedamp drainage stoppage.

In one month, reservoir pressure becomes higher than the atmospheric one. In this situation, there is a risk that gas could rise to the surface uncontrollably. This information must be taken into account in the planning of duration of periodic exploitation stoppages.

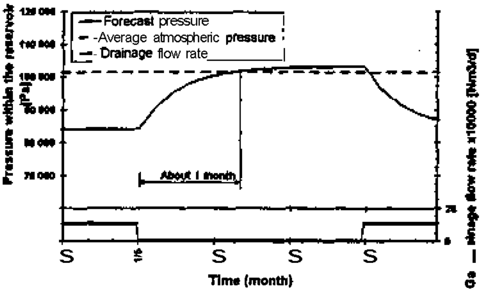


Figure 4. Cessation of gas drainage - Reservoir Saint-Charles - Reservoir pressure

4 CONCLUSION

The research carried out at **INERIS** resulted in a reliable and appropriate method for firedamp drainage modelling from **the** closed mines reservoirs.

The method has already been applied in an operational manner for several French drainage installations. The results of the simulations carried out indicate that analytical modelling is a very useful tool for improving our knowledge of firedamp reservoirs behaviour and for optimising the gas **drainage** processes.

The methodology is intended to forecasting of drainage parameters (reservoir pressure and methane content) in the function of planned level of collected gas flow rate.

It can be also used for predicting reservoir pressure evolution after periodic or definitive drainage stoppage. In the case of studied firedamp drainage site from Lorrain coal basin, the simulations carried out show that the reservoir pressure increases up to an equilibrium pressure greater than the atmospheric pressure about 1 month after drainage stoppage.

5 **ACKOWLEDGEMENTS**

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