The emissions of gases from abandoned mines : role of atmospheric pressure changes and air temperature on the surface

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Abstract Intrinsic parameters influence abandoned mine gas emissions. Independently of the presence or not of noxious gas in mine voids, meteorological factors influenced directly the gas outflow or inflow.

Measurement stations were installed in the exits located in abandoned mines of the iron Lorraine basin, the Lorraine and the North East France coal basins to enhance the gas flow behaviour.

Closure methods of the mines and exits from the abandoned mines are quite different.

For the first, shafts are associated with adits. Some of them are closed with bars to avoid people entrance into abandoned mine workings but gas flow is enabled.

For the second, there are essentially shafts which are secured. Some of them are equipped with a vent to enable outflow of the mine gas in specific conditions.

Mine gas parameters were measured. Besides, external parameters like temperature and atmospheric pressure were monitored.

Gas flow can be influenced mainly by the temperature difference between external atmosphere and mine workings (in iron mines, which can be considered as an open system) while atmospheric pressure influences gas flow in the coal mines, which can be considered as closed systems.

Modelling has confirmed the differential pressure value measured that exceeds friction losses.

Key words Mine gas emission · Atmospheric pressure · Air temperature on the surface · Exits · Open or closed old mining voids

Introduction

Some underground abandoned mines may continue to be vented to the atmosphere through wells, portals or shafts...Some, which are not mechanically ventilated, can contain noxious gas.

Noxious gas emissions can occur when gas migrates to the surface through cracks and fissures in the strata covering the abandoned mine.

The following factors influence abandoned mine gas emissions:

- time since abandonment (Pokryszka et al., 2005);
- gas content and adsorption characteristics of coal for coal mines;
- gas flow capacity of the mine;
- mine flooding;
- presence of vent holes and;
- mine seals...

Independently of these intrinsic parameters that directly induced the composition and the quantity of noxious gas produced and the emitted gas location, factors external from the abandoned mine such as temperature on the surface, atmospheric pressure, speed and direction of the wind have also effects on mine gas outflow or atmospheric gas inflow.

The aim of this paper is not to evaluate mine gas intensity. It is to enhance the understanding of these external parameters on gas outflow from underground mine voids that can contain or not noxious gas. Scientific publications show that gas outflows from abandoned mines or gas inflows are influenced by various external factors. Pokryszka and Grabowski (2004) highlighted the link between external temperature as well as direction and intensity of gas flow in the Moyeuvre iron ore lorain mine. The atmospheric pressure does not have any significant influence on gas flow. On the contrary, Burrel and Whitworth (2000), Strakos (2001) and Senovsky & Trunecek (2001) have written that noxious gas could flow out after an atmospheric pressure drop. The role of atmospheric pressure on noxious gas emission in firedamp mines has been studied for a long time: Lagrange (1924), Harries (1926), Carter and Durst (1995).

To understand the problematic, some exits in different abandoned mines (iron mines in Lorainne, coal mines in Lorraine and in North East France) were equipped with specific devices. Several parameters were monitored and the results were analysed. A modelling is also proposed to evaluate the flow strength in different cases.

These measurements are important to do because it will be shown, in some cases, that no gas will be detected even if there is some noxious gas in the abandoned mines.

Studied sites

The Lorraine coal basin

Coal extraction was made using shafts due to the occurrence of the coal seams (depth more than one hundred meters).
This basin presents variations in surface altitude (from 200 to 400 m NGF [Nivellement Général de la France that is to say , height when positive or depth when negative relatively to the sea level which is considered to be equal to 0 m NGF] in different sectors of the mine called “La Houve”. At the end of exploitation, in early 2000’s, dewatering was stopped and the exits were closed (with concrete plug or concrete slab). Some were equipped with a vent to enable gas exit in specific conditions. A vent or a venting borehole (when not put on a shaft) or a flare is a pipe in connection with the old mine workings. It is equipped with a flame arrestor and a check and relief valve. The check and relief valve should inhibit any intake of atmospheric air and is set to only open if the difference in pressure between inside of the pipe and outside exceeds 220 Pa (for Lorraine coal basin).
Two exits which were not under gas capture stations influence were equipped with measurement stations: one shaft (Barrois) and one venting borehole (SDEC OUEST 1).

Fig. 1 Photographs of the venting borehole SDEC OUEST 1 (left) and Barrois shaft with a vent (right) (Lorraine coal basin)

The North and Pas-de-Calais coal basin

Coal extraction was made using the shafts due to the depth of the coal seams’ occurrence. The shafts were numerous (about 150 in the Eastern part of the basin, which is not under gas capture influence). Some venting boreholes were equipped with specific monitoring system in this part. This basin does not present significant variations in altitude.

The Lorraine iron basin

This basin is divided into three main parts (the northern-one, the central-one and the southern-one), separated by the faults. The access to the mines was with shafts and adits. Shafts are located usually on the tops of the hills while adits are located on the hillsides. Iron ore extraction has begun with scrapings on the hillsides.
This basin presents variation in surface altitude (in the northern part, from 355 to 440 m NGF for the shafts and from 210 to335 m NGF for the adits). Some exits are closed by a grated gate to prevent from entering into old mining workings but gas entrance and exit are enabled. Several exits (see Fig 2 for example) were equipped with a measurement and monitoring station (see § Materials and methods).

Fig. 2 Algrange adit and François shaft (Lorraine iron basin)

Materials and methods

A monitoring system was installed on several exits in order to understand gas flow mechanisms and to evaluate mine gas composition in time for various abandoned mines. Several parameters were measured:

- External parameters such as atmospheric pressure and air temperature on the surface.
- Gas parameters such as gas velocity and flow direction, O_2, CO_2, and CH_4 gas content, radon volumetric activity, gas temperature, differential pressure.

Fig. 3 shows a typical measurement and monitoring station.

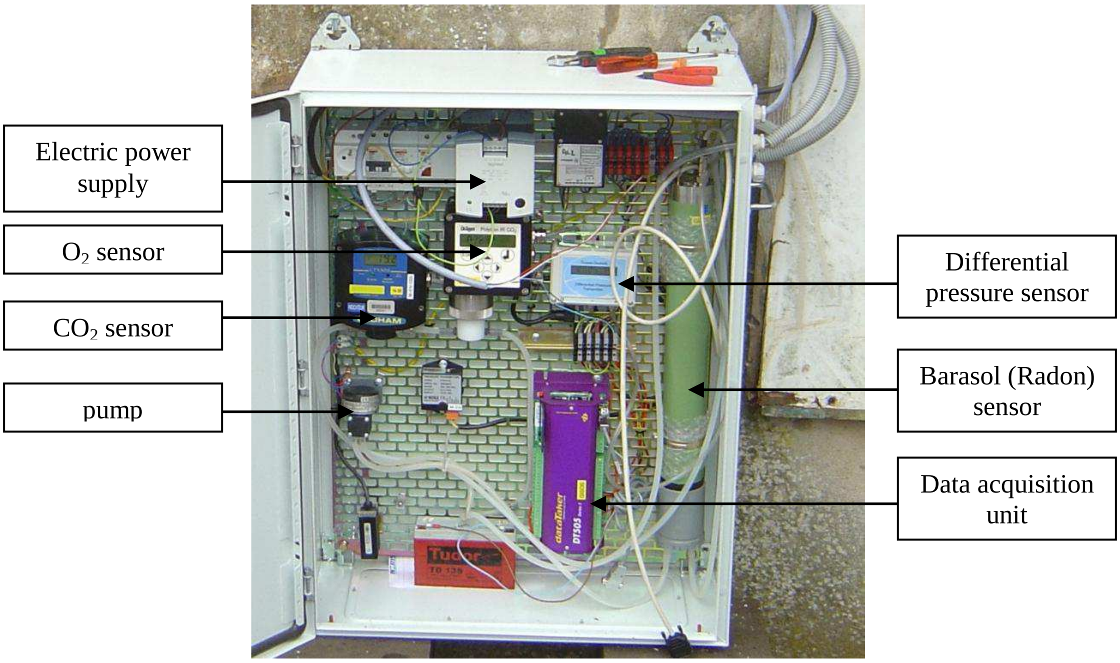

Fig. 3 Measurement and monitoring station

Results and discussion

Lorrain coal basin

A monitoring station was installed at Barrois shaft in October 2007. The recorded measurements are shown on Fig. 4.

A differential pressure build-up was observed with a gas outflow: CH_4 content is close to 100 % volume, CO_2 content is almost 3% volume and radon volumetric activity is about 2000 Bq/$m^{3.}$

The variations in differential pressure (P_{diff}) are opposite to the variations in atmospheric pressure, but there is no relation with the external temperature.

This behaviour is typical and has already been observed in other coal basins where the mine voids represent a significant volume and where exits between mine and surface are closed shafts out of gas capture influence (gas drainage station exits in the mid-part of the basin but its influence (represented by negative differential pressure) is neglected at a given distance, like in the eastern part of the North and Pas-de-Calais basin).

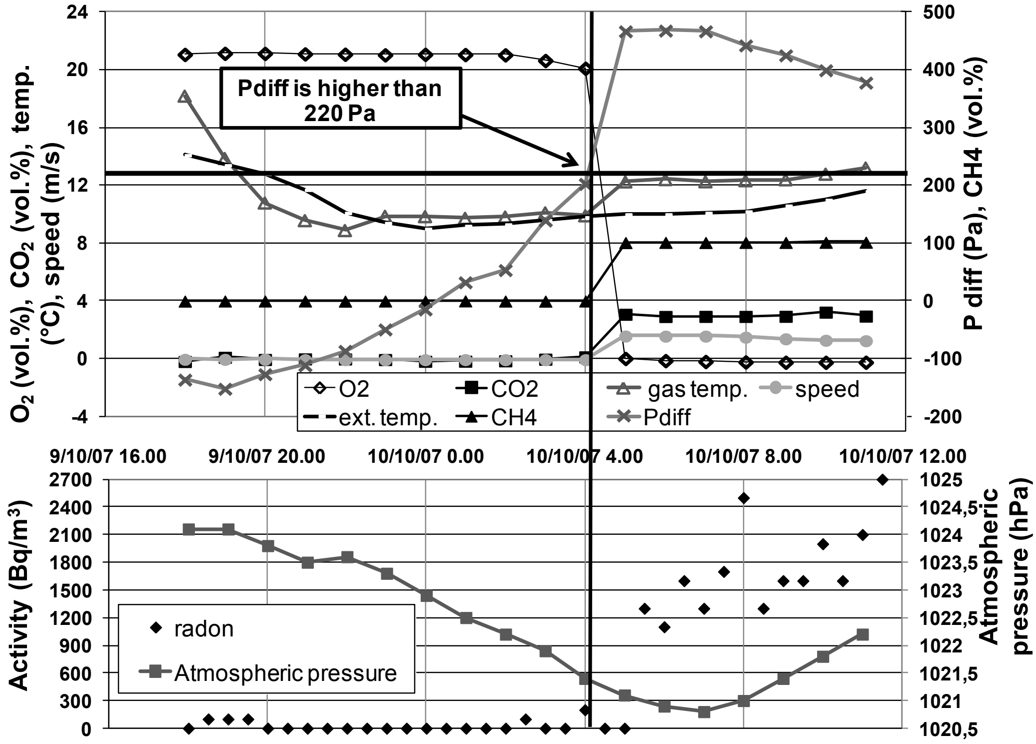

Fig. 4 Data recorded at Barrois shaft from 9/10/2007 to 10/10/2007 (Lorraine coal basin)

The North and Pas-de-Calais coal basin

It was observed for all exits equipped or not with a vent and for venting boreholes that the differential pressure shows variations that are the opposite of those of the atmospheric pressure (Lagny, 2005). The decrease or the increase of the atmospheric pressure induced variations of P_{diff} which are varying and can be included for example between -550 Pa and +2000 Pa (see Fig. 5 for S11 borehole located at the Vieux Condé mine).

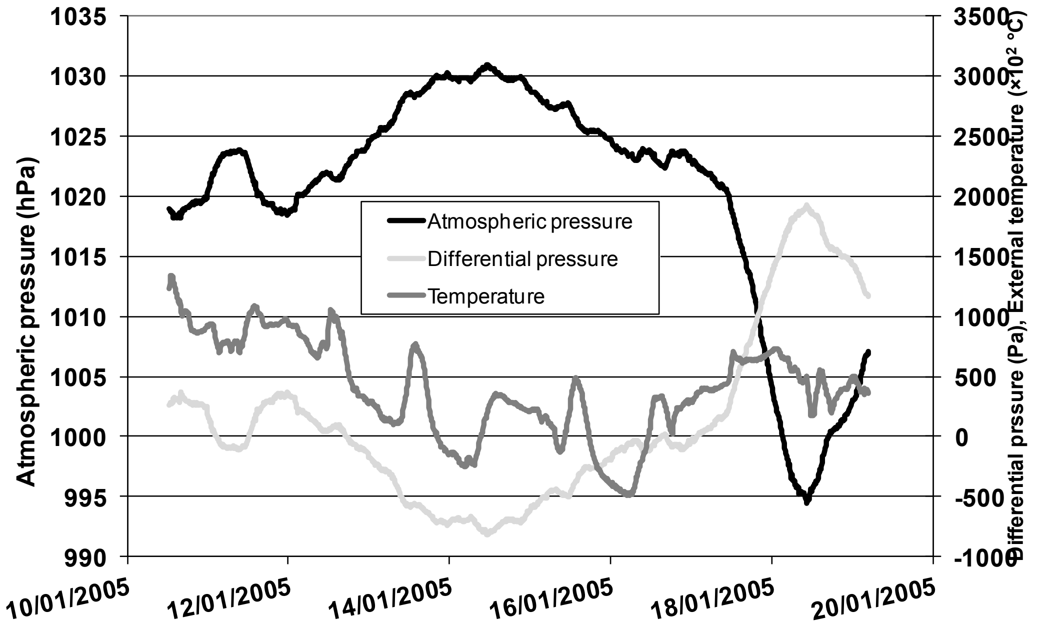

Fig. 5 Atmospheric pressure, differential pressure and air temperature on the surface over the time (recorded during ten days) on the S11 venting borehole at the Vieux Condé mine (Eastern part of the North and Pas-de-Calais coal basin)

The impact of air temperature on the surface is smaller: temperature variations comprised between 8 and 25°C induce pressure variation less than 300 Pa (relation observed on the S15 venting borehole at the Raismes concession but not on the S11 venting borehole).

The Lorraine iron basin

CO_2 volume gas content presents seasonal variations as do radon volumetric activity and oxygen content. According to the season and for each exit, it is observed that gas flow direction changes due to the variations of air temperature on the surface. No relation is observed between gas flow direction and atmospheric pressure (Fig.6).

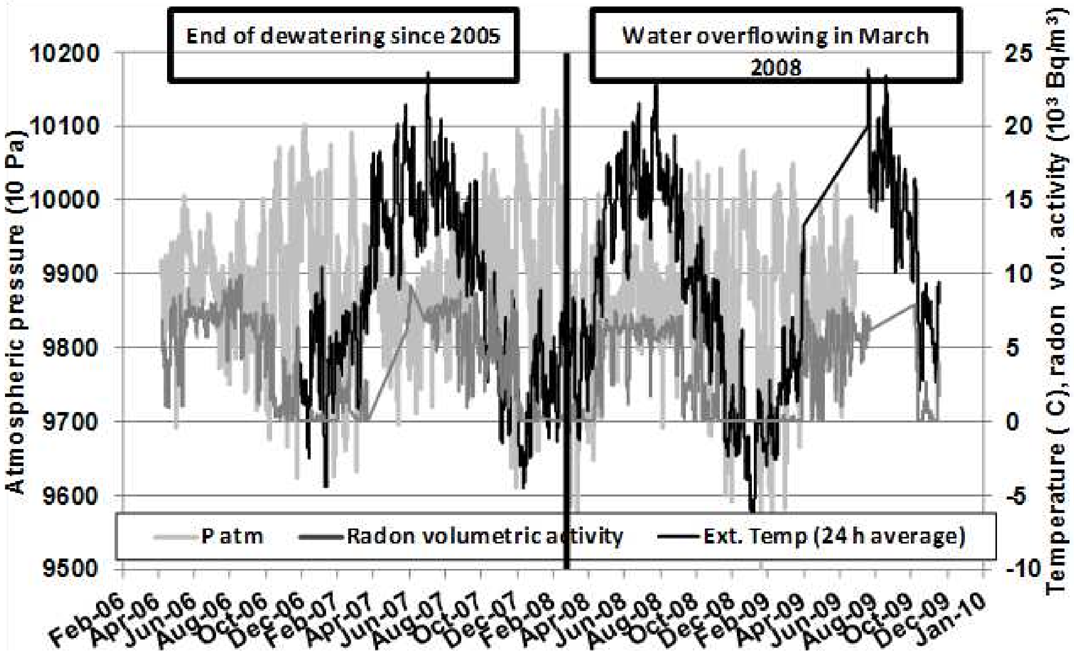

Fig. 6 Radon volumetric activity, atmospheric pressure and air temperature on the surface registered at Algrange adit (Lorraine iron basin)

Similar results (Fig. 7) were observed in G37 adit, which has been equipped with a monitoring station more than ten years ago and which is located in Moyeuvre town, in the low part of North iron basin. Gas flow direction is induced by the air temperature on the surface. Decreases in O_2 gas content (which can reach less than 13% vol.) were observed with the increases of CO_2 content (which can reach more than 4% vol.) during summer periods.

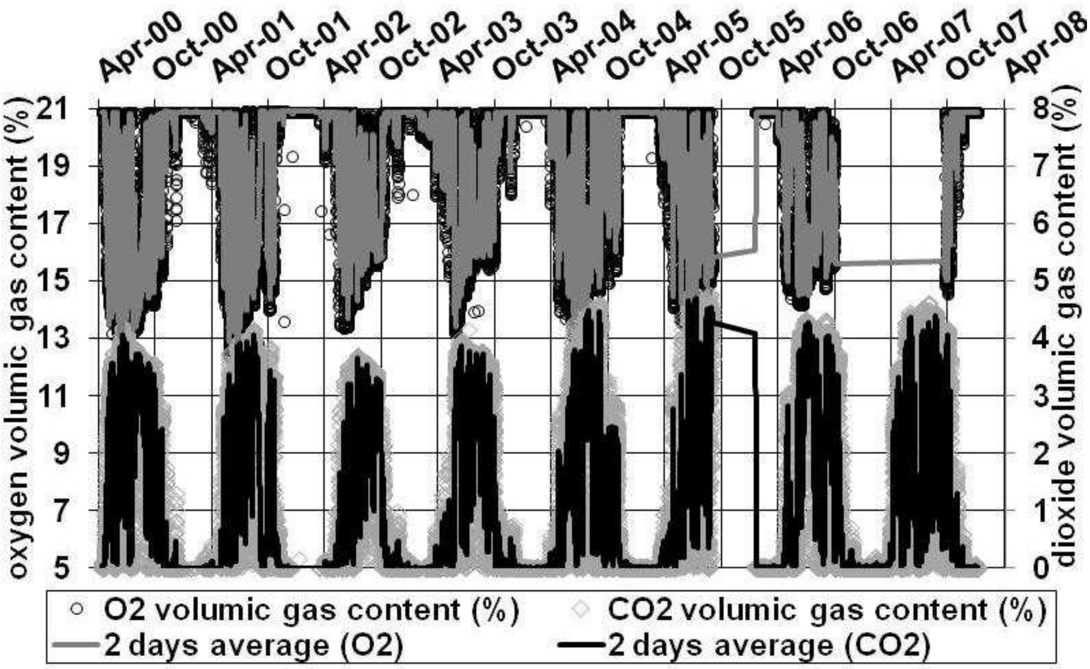

Fig. 7 Data registered on G37 adit (Moyeuvre-Grande town) from April 2000 to April 2008 (Lorraine iron basin)

Modelling

The Lorraine iron basin

When the internal temperature (which is quite constant and equal to 11-12°C) is larger than the external one, massive thermal venting induces colder external air (heavier) to enter through the low openings while, the warmer mine gas (lighter) flows out through the upper openings.
As mine gas temperature is almost constant, the variation of the air temperature on the surface value will induce change in the direction of the flow. The pressure induced (or the push) can range from -5 to 25 Pa (which is in the order of magnitude of the differential pressure measured in situ at Algrange adit for example) with a difference of temperature between -5 to 25°C, a blow speed equal to 0 and a height difference of 30 meters (Axley, 2001).
The push, p_s, is the driving force and counterbalances the entrance (or exit) air losses.

$$p_s = (\rho_o - \rho_i) g . \Delta z$$

where : ρ_o = volumic mass of the external gas (kg/m^3);
ρ_i = volumic mass of the internal gas (kg/m^3);
g = gravity acceleration (m^2/s);
Δz = height difference (m).

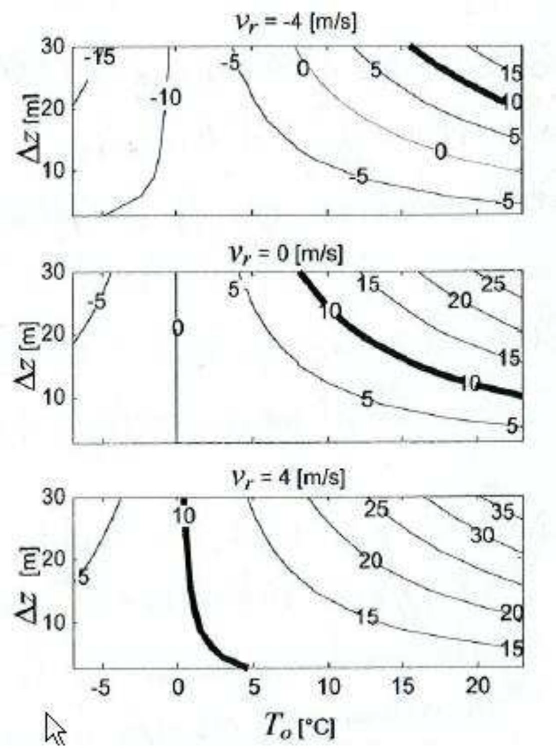

Fig 8 shows the value of the driving force (black curves) which includes wind (v_r) and thermal (T_o) effects.
Fig. 8 Driving force due to wind and thermal effects (Axley, 2001)

The North and Pas-de-Calais coal basin

A numerical simulation was made (Lagny, 2005) for the eastern part of North and Pas-de-Calais coal basin. In particular, a decrease in atmospheric pressure like those observed on S11 (Taffin) borehole was simulated and the differential pressure was calculated.
Assumptions were taken concerning:

- initial pressure in mining voids;
- a flooding time of mine voids of 24 years;
- a desorption capacity which decreases linearly with time;
- some average characteristics for the 150 shafts and the venting boreholes located in this basin's part;
- the use of perfect gases law for calculation of mol number in the mining voids at each calculation step;
- a voids volume of 62.4 Mm^3 which decreases linearly with flooding and with time;
- an initial pressure in the borehole equal to 1016 hPa;
- a mine gas density closed to 0.8;
- 150 shafts whose intrinsic permeability is around 10^{-10} m^2, the diameter is taken equal to 3 m, the average depth of the upper exploited level is 145 m;
- mine gas exit through the recovery is neglected.

The flow (in m^3/s) in a venting borehole is described by the equation which links it to the pressure drop and to the differences of the square of the pressure.

$$Q(t) = \sqrt{\frac{288. d^5.(P^2_{rés}(t) - P^2_{atm}(t))}{804372. \lambda. \delta. l. T}}$$

where : d = borehole diameter (m);
λ= drop losses, dimensionless number;
l = borehole length (m);
δ = gas density, dimensionless number;
T = borehole gas temperature (K);
$P_{rés}$ = void pressure at the base of the borehole (Pa);
P_{atm} = atmospheric pressure (Pa).

The results are shown on Fig. 9.

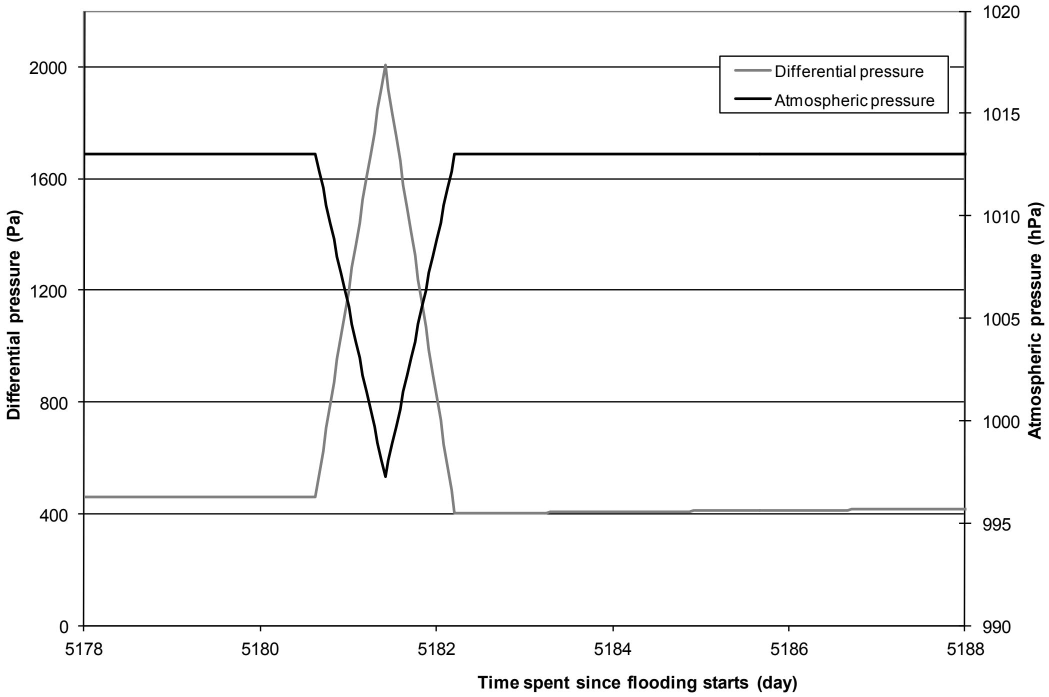

Fig. 9 Differential pressure calculated before, during and after an atmospheric pressure drop

The differential pressure calculated is clearly similar to those registered in January 2005 (Fig. 5). Atmospheric pressure variations induce differential pressure variations which are opposite.

Discussion

The abandoned mine voids, which consist of a closed system (shafts closed off and/or filled-in like in the coal mines previously presented) operate as follows:
The variations in atmospheric pressure lead to fairly significant differential pressure. So, the atmospheric pressure serves as the main parameter driving mine gas.
In the iron basin, natural thermal convection plays a major role in the creation of the flow between old mine workings and the surface. This phenomenon is due to the difference between the air temperature on the surface and the temperature in the voids. Thermal convection is facilitated by a surface topography difference and by the methods of closing the exits.

Conclusions

The results of the present study clearly show that the main motor of gas migration from the old mining works towards the surface is not the same in the various basins which were analysed.
In one case (abandoned mines defined as an open system), the external temperature is the main parameter; in the other case (when the abandoned mines are defined as a closed system) the atmospheric pressure variations are then the crucial parameter.

The present results should improve the interpretation of the gas measurements made at abandoned mines exits and boreholes. Atmospheric conditions and abandoned mines configurations should be taken into account to understand data obtained in various contexts.
It is especially important to take care of these observations because, in some cases, measurements made in specific atmospheric conditions will show that no gas is emitted from abandoned mines although mines voids could contain noxious gases which could be emitted in others atmospheric conditions. This could induce mistakes on gas emission level estimation or on the detection and location of abandoned shaft by infra-red thermo graphic method (Donnely and McCann, 2000), or on the measurement of radon volumetric activity which value depends, notably, on atmospheric conditions (see IRSN (Institut de Radioprotection et de Sûreté Nucléaire) publications) or on the behaviour of venting boreholes connected with abandoned mines...

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