Risk assessment of reversible storage of O_2 and CO_2 in salt caverns for large-scale energy storage

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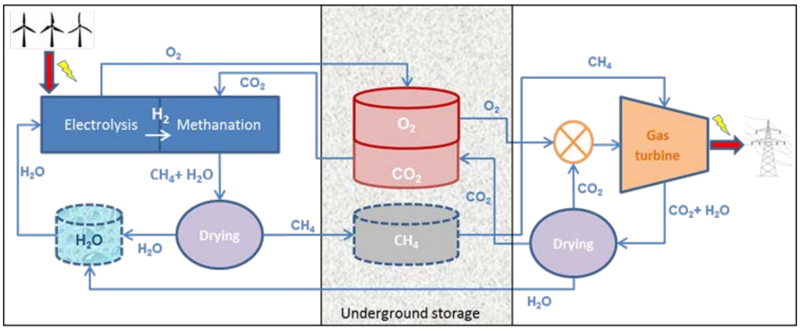
Introduction

Power-to-gas technologies represent one possibility for large-scale energy storage. In the case of the FluidStory project, the EMO (for Electrolysis – Methanation – Oxycombustion) technology is studied. This process operates in closed loop. The principle is that excessive electric power is used for water electrolysis, thus creating H_2 and O_2. Then, in the methanation step, H_2 is combined with CO_2 to form CH_4, which can be stored and then, when power is needed, burned in an oxyfuel unit. The oxygen for this combustion is recycled from the electrolysis. Similarly, CO_2 resulting from oxycombustion is captured and reused in the methanation step. Therefore, the EMO process implies temporary storage of large amount of O_2, CO_2 and CH_4. Figure 1 details the EMO concept.



Adapted from L. Zibell, EMO concept, preliminary R&D program, 2013

Fig. 1: Concept of EMO from the FLUIDSTORY project

While CH_4 reversible storage is a standard industry practice since decades, there is little previous experience in storing large quantities of O_2 and CO_2. One of the important uncertainties to address for this technology is thus to assess the potential risks of reversible stores of CO_2 and O_2.

The risk management approach is broadly based on the principles of the ISO31000 norm. The first step establishes the context, defining the perimeter of the study. The second step is risk identification, where the various potential scenarios are listed, irrespective of their gravity. The third step is risk analysis where the risks are ranked, usually according to two criteria: severity and likelihood. The fourth step is risk evaluation, where the risks are compared to criteria determining if the risks are acceptable or not, in which case risk treatment is necessary.

Context

There are several options for storing gases underground, but currently, there is a consensus (Bérest and Brouard, 2003) that salt caverns are the best compromise between safety, feasibility and economic charge. The main option is to use two caverns: one for storing O_2 and the other for storing CO_2. In this paper, the base case is that the two caverns are specifically developed for that purpose. Other potential options would be to re-use existing caverns, or to store O_2 and CO_2 in the same cavern.

Risk identification

Methods for risk identification can broadly be separated in two categories: systematic and non-systematic methods. As the case studied here is generic (i.e. not applied to a particular site but rather to a technology in general), a non-systematic method was preferred. The method consists in using generic risk diagrams, developed by BRGM for subsurface exploitation activities. Those risk diagrams are similar to typical bow-tie diagrams with a central event and upstream arcs representing potential causes, and downstream arcs representing potential consequences.

Fig. 2: Principle of a bow-tie diagram

A small workshop was organised with experts from the project and the generic diagrams where adapted to the case of CO_2 and O_2 storage in salt caverns. Among the scenarios generated (i.e. the unique path from a cause to a consequence), only those differing from the case of natural gas seasonal storage are considered in the study, as natural gas storage residual risks are already routinely managed.

Here are the main conclusions from this part:

A first source of uncertainties (and thus of risk) is about the cycles for CO_2 and O_2 storage. The economic model is different from those of natural gas, seasonal, which is highly correlated with periods of cold. Indeed, electricity supply is not as stable as natural gas supply and there may be some heterogeneity in injection of O_2 or CO_2. First economic estimations show that the main interest is in inter-seasonal storage, which in the end would lead to annual cycles such as natural gas cycles. Yet, we cannot rule out shorter cycles at this early stage. The effect of shorter cycles would be to augment the mechanical solicitation of the cavern with more repetitions of injection and extraction of gases. Another uncertainty lies in the effective properties of the gas stock underground: dedicated surface infrastructure should be present in order to control the gas composition (purity) and conditions (pressure and temperature should remain acceptable).

The second main source of uncertainty relates to the reactive nature of both O_2 and CO_2. In particular, O_2 can pose a risk of burning metal if there is no care in controlling the speed of the gas in the tube. Regarding CO_2, it can transform in a weak acid if wetted and thus provoke corrosion of tubings and carbonatation of cement. The risk of alteration of the cavern is considered low as salt is not reactive with these products.

The third main source of uncertainty we identified is the thermal behaviour of the gases in the cavern, with a particular concern for operators being the risk of hydrates formation.

Risk analysis

For this part, we decided to create a synthetic, but representative case, as it would be easier to rank the previously identified scenarios. We defined the case study in accordance with the partners of the FluidStory project working on cavern modelling. We consider a cylindrical cavern with a height of 200 m, a radius of 30 m and a volume of 546 000 m3, at depth between 700 and 900 m. Geostatic pressure at 800 m is around 17 MPa and temperature is 34 °C. Residual brine represents 7% in volume. For O_2, an annual cycle is defined this way: a 3 months rest period with maximal stock (around 12.5 MPa); a 2 months withdrawal period at constant mass rate; a 1 month rest period with a minimal stock (around 3 MPa); a 6 month injection period at constant mass rate and temperature of 60°C. For CO_2, the cycle is opposite: CO_2 is extracted when O_2 is injected and vice versa.

In addition, conceptual models (such as influence diagrams) are used in order to make a (semi) quantitative analysis. The models are completed, where necessary, by experts opinion, which can inform the results.

Perspective and conclusion

The risk evaluation represents a challenge at this stage, as there are no existing robust criteria for comparing the risk. Instead, a typical ALARP (As Low As Reasonably Practicable) criterion must be used: all risk reduction effort should be considered as long as the benefits outweighs the costs.

The main outcome of this work is to make informed recommendations based on evidence. At this early stage of development, there are still many options to be considered and modelled in the economic analysis, in the EMO processes, and in the underground stores. Risk assessment is particularly challenging as all the options can influence the risks. At this stage, it is thus important to be able to represent and compute a large quantity of scenarios efficiently.

The preliminary conclusion from the FluidStory project is that, despite the large uncertainties, O_2 and CO_2 should be safely stored in salt caverns, based on the comprehensive existing experience in storing natural gas.

References

Bérest P., Brouard B. 2003. Safety of salt caverns used for underground storage. Oil & Gas Science and Technology Journal – Rev. IFP, Vol. 58, 3:361-384