Portugal Underground Gas Storage in Salt Caverns

1. Introduction
The crises between Russia and Ukraine in 2009, have demonstrated the European Union energy system vulnerability as some countries threaten to break natural gas stocks. This scenario is compounded by the high EU dependence of the Natural Gas from Russia. In this context the underground storage of natural gas is presented with a good solution to minimize this problem.

This paper is a study of the potential for underground storage of gas in salt caverns in Portugal, in order to find the volume of gas that can be stored in the national territory. It is emphasized that in Portugal there are plenty of salt dome formations that can provide solutions for storage. For a better understanding, a characterization of the global market for gas will be made, giving greater focus to the current situation of the European Union, and described the methodologies most used for storing gas underground.

2. World Market
In this chapter will be characterized the global market for natural gas (Reserves, Production and Consumption), placing greater emphasis on the state of the EU.

2.1 Reserves
The proven reserves worldwide have grown steadily over the years, in 1980 were at the level of 80 000 bcm, rising to 180 000 bcm in 2006 (GILARDONI, 2008).

The evolution of proven global reserves, and the R / P ratio (reserves / production) is shown in Graphic 1. The Graphic shows that, at current production level, the 2006 proven reserves would be sufficient for a period of 63 years.

2.1.1 European Union
The main reserves of the EU are held by two countries: the Netherlands and the UK. Until this day the reserves have been declining, reaching 2 500 bcm in 2006, which represents a ratio (R / P) of 13 years (Graphic 2). This trend should not change because all the gas fields probably have already been discovered. (GILARDONI, 2008)

2.2 Production
World production increased from 1500 to 3000 bcm between 1980 and 2006, and is predicted that this trend will continue in forthcoming years. This growth is explained
by increased exploration and production technologies that allowed reaching previously unattainable gas fields.

The Former Soviet Union presents itself as the largest producer in the world. This fact is due to the growing dependence of the EU. In 2006 the production in the region stood at 612 bcm and it is estimated that in 2030 its production will grow up to 1 280 bcm (GILARDONI, 2008).

3. **EU Production**

Production in Europe peaked in 2001 and has, since then, started a steady falling. In absolute terms, production fell from 220 bcm in 2001 to 190 bcm in 2006, and this trend should continue in the forthcoming.

3.1 **World Consumption**

As is shown in Graphic 4, the weight of natural gas in the world energy mix has been increasing consistently since 1980, from 20% of energy consumption to 24% in 2003. Demand for natural gas increased from 1 448 bcm in 1980 to nearly 3 000 bcm in 2006. The growing penetration of the gas market is explained by the fact that this fuel is very competitive with coal in power generation, has multiple applications and is the cleanest of the fossil fuels.

3.1.1 **Europe Consumption**

Natural Gas in Europe is the only major energy source that has been steadily increasing, reaching the second place of the energy sources consumed in 1996 (Graphic 5). The main source of energy remains the Oil due to its use in the transportation sector. None the less, its share in the European energy mix has undergone a steady decline from 47% to 41% between 1980 and 2006.

Petroleum and Coal have both been gradually replaced by gas in power generation, seeking to respond to the directives imposed by the Kyoto Protocol. In absolute terms the demand for gas in Europe has grown from 223bcm in 1980 to 467 bcm in 2006, with Germany, France, Great Britain and Italy as the largest consumers of the EU.

4. **Underground Gas Storage**

Underground storage is a key element of most modern energy systems. The main function of gas storage is to maintain the
balance between supply and demand of gas, suppressing peak demand. However this type of storage is also used for a variety of factors:

- Balancing the gas flow in pipelines
- Comply with contracts made, keeping the delivery rate,
- Flatten production in periods of low consumption,-
- To market speculation;
- To reduce the volatility of the price;
- Energy security for Europe to deal with the excessive dependence on Russia.

4.1 Underground Gas Storage

History

In 1915 was recorded the first gas storage in Canada installed in depleted oil fields. In 1946 the first aquifer storage was installed in U.S. Later, in 1961, the first salt caverns were built for underground storage of natural gas. One of the newest methods dates back to 1963 when it was installed in the storage Abandoned mines in the U.S., being a widely underutilized.

4.2 Underground Gas Storage in the World

The concentration and type of facilities varies from region to region, in 2003 the total world volume of gas stored was 340 bcm. Of this, 37% were in the American continent. The two countries with largest volumes of stored gas are the U.S. and Russia with 90 and 110 bcm respectively.

4.2.1 In Europe

In Europe there are nearly 200 storage facilities with Germany, Britain, Italy, France and Spain being countries with the highest number of installations. Germany has about 18.34 bcm of natural gas stored, corresponding to 75 days of domestic consumption. On the other hand, France has 11.86 bcm, equivalent to 91 days of domestic consumption without the need for external supplies.

Portugal has, at present, 323 MM m$^3$ of stored gas, distributed among storages in four salt caverns at Carriço region in the form of Natural Gas and LNG (Liquefied Natural Gas) in Sines. This storage represents nearly 22 days of domestic consumption without the need for external supply. As an example, compared to what goes on in France (91-day supply) Portugal must increase the volume of stored gas.

Currently the Company REN ARMazenamento has a development plan at Carriço which includes the construction of 25 salt caverns. When completed, these caverns will allow storing 1 250 MM m$^3$ of natural gas in this region alone.

Beyond this region, it is expected an increase of the storage capacity at Sines by building a new reservoir of 150,000 m$^3$, to be operational in 2012 (COSTA, 2009).

5. Underground storage properties

The gas storage is possible only in geological structures that have the appropriate characteristics to their fitness, in terms of stability and security. The three methods most used are: Depleted oil and gas fields, aquifers and salt caverns. Each installation has its own physical characteristics: porosity, permeability, retention capacity, and economic impact: costs of installation and maintenance deliverability rates and capacity cycles.

5.1 Depleted Oil/Gas Fields

This type of storage is the most used for underground storage. The gas is held in porous and permeable structures that have
stored oil efficiently in the past. These are, on average, cheaper and easier to develop because of their well known geological characteristics, as well as enabling the use of the facilities used during the previous stage of production of the reservoir. To keep the operating pressure inside the tank, it is necessary to continuously maintain 50-60% of existing gas as "base gas". As gas previously existed in these formations it is not necessary to inject the entire base gas which becomes physically unrecoverable.

5.2 Aquifers

The aquifers may be used for underground storage if the volumes and isolation conditions are adequate. In general, storage in aquifers is more expensive than depleted fields. (COMFORT, 2009). Normally there is still not a thorough knowledge of the physical and geological structures, hence the need for previous studies to evaluate the sustainability of the aquifer. If validated, all structures associated with the storage should be installed resulting in high development costs. As the aquifer initially contains water, there is no gas in the formation so 80% of the injected gas will form the base of gas needed to provide the pressure needed to obtain satisfactory deliverability rates. Usually these facilities are built when the price of gas is at lower levels (APPI, 2005).

5.3 Salt Cavities

When a saline structure is discovered and identified as having potential for development of underground storage for natural gas, the cave is created through a process called "Cavern Leaching" where it is injected fresh water that will dissolve the salt producing brine. Then this brine is extracted, resulting in a void that will be used to store natural gas. This type of storage requires only about 20 to 30% of base gas and provides 10 to 12 cycles of injection and extraction per year.

Of the three structures, this is the most expensive because it takes large volumes of water to dissolve the salt being generated large volumes of brine, which have to be processed. However the high rates of delivery and the low volume of base gas help to make it economically attractive (COMFORT, 2006).
6. Potential for underground storage in the Lusitanian basin

In the absence of depleted reservoirs or aquifers available the solution found was the installation of storage in salt caverns. In order to reach this goal, geographic criteria of risk was defined, identifying potential storage areas. The criteria accepted were:

- 20km distance from airports
- 100m distance from roads, and 200m distance from civil buildings
- Areas with low slope
- Out of agricultural and ecological reserve.
- Proximity to pipelines and ocean.

6.1 Procedure

The map shown in Figure 4 is the result of the first prospecting work in 1943, which recognized the existence of salts in the region of Leiria, Caldas da Rainha and Obidos. The criteria will be applied on this map, pointing out areas validated by them.

6.1.1 20km distance from airports

Identifying the airports in the study area and setting up a perimeter of 20km in each of them could limit the study to the diapiric area of Caldas da Rainha (Figure 5).

6.1.2 100 m distance from roads and 200 m distance from civil buildings

By applying a buffer to roads and civil occupation spaces, it was possible to identify potential areas that are in the diapiric of Caldas da Rainha.
6.1.3 Areas with low slope

As it can be seen in Figure 7, generally the entire study area is a flat area. Only in the southern part will be excluded potential areas identified in blue.

As it can be seen in Figure 8, several potential areas will be excluded because they are within the Ecological Reserve. However, other areas are on Mata Valado dos Frades a sensitive area for storage.

- Caldas da rainha

6.1.4 Out of agricultural and ecological reserve

- Nazaré

In this area, virtually all areas will be excluded, leaving the three areas identified in blue at the south.
7. Calculate volumes storable

Now that all areas of interest have been found, it’s time to calculate the gas volume that may be stored in these areas. Assuming the parameters used in the case study (Carriço): Spacing between shafts of cavities 300 m and volume of gas stored per cave by 50 MMm³.

7.1 First Scenario

In the first scenario all the roads in the region were considered, resulting in several areas by county.

In this case you can store 1bcm of natural gas equivalent to 84 days of Portuguese domestic consumption.

<table>
<thead>
<tr>
<th>Id</th>
<th>County</th>
<th>Area (m²)</th>
<th>No of cavities</th>
<th>Total gas stored (10⁶ m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nazaré</td>
<td>22731.14</td>
<td>1</td>
<td>50</td>
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<tr>
<td>2</td>
<td>Nazaré</td>
<td>40238.38</td>
<td>1</td>
<td>50</td>
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<td>3</td>
<td>Nazaré</td>
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</tr>
<tr>
<td>4</td>
<td>Nazaré</td>
<td>79234.48</td>
<td>1</td>
<td>50</td>
</tr>
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<td>5</td>
<td>Nazaré</td>
<td>82400.78</td>
<td>1</td>
<td>50</td>
</tr>
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<td>6</td>
<td>Nazaré</td>
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<td>1</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>Nazaré</td>
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<td>50</td>
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<td>Nazaré</td>
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<td>11</td>
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<td>12</td>
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</tbody>
</table>

**Total gas stored**: 1000

7.2 Second Scenario

Alternatively, was admitted the clustering of all existing areas by county, and obtained
the values shown in Table 2. The 1.65 bcm that can be stored account for 41% of average annual consumption in Portugal.

<table>
<thead>
<tr>
<th>County</th>
<th>Area (m²)</th>
<th>Nº of cavities</th>
<th>Total gas stored (10⁶ m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peniche</td>
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<td>1200</td>
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<tr>
<td>Total of gas stored</td>
<td></td>
<td></td>
<td>1650</td>
</tr>
</tbody>
</table>

Table 2 – Scenario 2

7.3 Third Scenario
A third scenario is presented, assuming that the sensitive area of Mata Valade dos Frades would not be allowed to use for the requested storage. In this case the total volume of gas that could be stored would be 450 MM m³, equivalent to 41 days of domestic consumption of gas.

8. Environmental impacts during construction
The environmental impacts recorded in the case study were:

- Methane and carbon dioxide emissions
- Change of land use
- Impacts on underground and superficial waters
- Noise
- Impacts because of the brine disposal
- Impacts associated with water harvesting, drawdown of freatic level

9. Conclusions
During this work it was demonstrated the growing importance of storage facilities of natural gas in developing sustainable energy policies. For the EU this importance is even more relevant given the excessive dependence on the Russian gas.

In this context, Portugal can be positioned to function as strategic reserve for the EU and in the absence of domestic production can store gas from Algeria and Nigeria, and sell it to the countries in need.

The study focused on a geographical analysis of the risks associated with this type of facilities and must be validated by additional studies to evaluate the diapirics stability.

Still, this study demonstrated that Portugal has plenty of salt structures, and the region studied in the best case scenario, could be stored 1,973 bcm of natural gas, equivalent to 165 days of domestic consumption. Making Portugal the largest gas reserve European Union.

In these times of economic and financial crisis, the storage of Natural Gas and its commercialization may represent viable solutions for the future.

10. References


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