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POSSIBILITY OF ENERGY STORAGE IN SALT CAVERNS

1. INTRODUCTION

The comparison of energy storage possibility in the form of hydrogen and compressed air with well identified storage of natural gas process will be presented in this paper. The article concerns geological and mining conditions as well as environmental, social and legal issues for Polish coast region.

The storage of natural gas in salt caverns is a common practice in the world and after storage in depleted gas deposits and aquifers it is a third method as regards the amount of stored substances. In terms of energy demand during peak periods natural gas stored in salt caverns has a crucial role regarding both the seasonal and daily peaks. The share of natural gas in the installed capacity of power plants in Polish energy sector is relatively small and at present amounts approx. 3.28%.

Much less known are technologies of Compressed Air Energy Storage (CAES) and hydrogen storage in salt caverns. Nowadays these media in pure form are not used in energy industry and issue of their use for power generation is the subject of numerous research projects. Compressed air is used in gas power stations while hydrogen is a component of city gas which is used for power generation.

The authors of some publications [1] claim that there is not much difference between the storage of natural gas, city gas or hydrogen, however it seems that such an opinion is too optimistic. Admittedly according to the regulations concerning the existing surface and underground infrastructure it is possible to store and transport the mixtures of natural gas and hydrogen containing up to 10% of hydrogen.

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While discussing the possibility of using hydrogen and compressed air for in energy industry the methods and efficiency of their production of surplus power as well as storage capacity and utilization for power generation should be considered. This article is focused on possibility of storage in salt caverns and thus the information presented may also refer to a different purpose e.g. in petrochemical industry.

2. UNDERGROUND STORAGE AND THE USE OF CONCIDERED SUBSTANCES

2.1. Storage of natural gas and its use for energy purposes

At the moment in Europe there are over 300 caverns of natural gas in operation with a total capacity of 9.060 billion m^3 [12]. In Poland the capacity of existing caverns amounts approx. 581 million m^3 (according to PGNiG).

The system of power generation from natural gas is based on the classical gas turbine. To compress the air needed for supplying a turbine a compressor powered by the same turbine is used. As a result, approx. 50% of the energy produced by the combustion of natural gas is consumed to compress the air. The overall efficiency of such power plant does not exceed 39%.

For years many studies have been carried on increasing the efficiency of power plants by reducing the amount of energy needed to compress the air. In the case of CAES (Compressed Air Energy Storage) power plant compressed air is supplied from the underground caverns directly to the turbo-set what increase the efficiency of the entire installation. The air is compressed in a period of lower energy demand e.g. from renewable sources.

Currently there are two power plants operating in the CAES system in the world. The first one with a capacity of 290MW was built in 1978 in Huntorf (Germany) and the second power plant McIntosh with a capacity of 110MW was launched in 1991 in the USA. The efficiency of Huntorf power plant is 42% while the efficiency of the McIntosh power plants is 54% thanks to applied heat recovery unit [9].

2.2. Storage and use of hydrogen

Pure hydrogen is stored in salt caverns as a substance used in chemical and petrochemical industry. Such storage caverns already exist in Teeside in the UK (three caverns with a total volume of approx. 210 000 m^3) and two caverns in Texas in the United States (Clemens of approx. volume of 580 000 m^3 and Moss Buff of approx. volume 566 000 m^3) [1].

Hydrogen can be used to produce electricity in fuel cells or through combustion. The example of such a power plant is a small installation in Fusina (Italy) with a capacity of 12 MW. The cost of electric power generation in this plant however approx. 5 times exceeds the production costs in classic power plants.

2.3. Storage and use of compressed air

Since the launch of the first CAES plant in the 70s of the last century this technology has been rapidly developed. One of the effects is the technology of adiabatic compression and expansion of the air – Advanced Adiabatic CAES (AA-CAES) which may be used in the power plant. The main component of such a system is a reservoir of thermal energy which accumulates energy during compression of the air and then provides the energy for heating the air during its decompression. The heated air passing through the turbine generates electric power.

Such a solution would allow both to increase the efficiency of the process to a value exceeding 70% as well to eliminate combustion of natural gas and in the effect to reach the zero carbon dioxide emissions [14].

At the same time research is carried on an isothermal process of the air compression. In this concept the conditions of pressure and volume are so closely controlled that the pV curve during the air compression and expansion is as close as possible to the isothermal. This solution eliminates the need of heating the air and building a reservoir of thermal energy such as in the case of AA-CAES technology. The process takes place thanks to a slow compression, and efficient heat exchange with the environment [8].

Regardless of the technology development and the increase of plant efficiency internal energy of the compressed air is relatively small. The calorific value of natural gas is in fact 31 MJ/Nm^3 and the heating value of hydrogen 10.8 MJ/Nm^3 while the internal energy of compressed air is approx. 0.25 MJ/Nm^3. Thus the use of the air as a clean energy source would require providing much larger storage volumes and produced energy could be only used to cover the shortage of daily peak demand.

3. GENERAL REQUIREMENTS FOR STORAGE OF SUBSTANCES IN ROCK SALT DEPOSITS

3.1. General requirements for the rock salt deposits

As a standard it is assumed that the thickness of the salt deposit for the rational leaching of the storage caverns in traditional technology is 150 m. This thickness allows the leaching of caverns with a volume of over 100 000 m^3. It is possible to leach caverns with a volume 50 000–100 000 m^3 even for a much smaller thickness (60–100 m) [7] but it requires the use of different technology of leaching. The works on development of the technology of tunnel cavern leaching and control their shape are conducted currently by Gaz de France. They confirmed the possibility of leaching two caverns in salt deposits in Alaska and in northern France. The works on the leaching of tunnel caverns are also carried out by Gazprom which plans to locate such caverns in the Kaliningrad region within the Zechstein rock salt deposit.

The maximum depth of the caverns location is estimated at approx. 1800 m below the surface. In Eminence in the USA the gas storage cavern was located at the depth of up to 2150 m below the surface. However due to problems with convergence is it an argument against location of storage caverns at such depths.

3.2. General ecological requirements and formal regulations

Apart from geological conditions the basic problems limiting the possibility of leaching caverns in salt deposits are the environmental issues concerning the discharge of brine and legal regulations associated with licensing the investment. Nowadays in Poland the brine coming from leaching salt caverns is transferred to the borehole salt mine (Mogilno) or discharged into the Baltic Sea (Kosakowo). Brines are also discharged to the surface waters (from Silesian coal mines) and into underground structures as "non-reservoir storage of substances".

In addition to the above issues leaching salt caverns for storage of natural gas requires the meeting of a number of complex legal procedures in the field of mining and environmental protection. The key issues might be obtaining:

- the decision on environmental conditions of the project resulting from the requirements of the Act of 3 October 2008 concerning access to information about the environment and its protection, public participation in environmental protection and environmental impact assessments ([15], as amended);
- the project acceptance by the local government and the local community and positive opinion of the Regional Directorate of Environmental Protection on the project;
- the license for non-reservoir storage of substances in rock mass, resulting from the Act of 9 June 2011 – Geological and Mining Law ([16], as amended).

Disposal of brines from the leaching of salt caverns through their discharging to surface waters hardly can be considered. Restrictions in this respect are defined by the Act of 18th July 2001 r. Water Law [17] and the Regulation of the Minister of Environment of 18th November 2014 on the conditions of discharging waste into the surface waters or soils and on substances particularly harmful for water environment [18].

The European Union water policy in Directive 2000/60 / EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, known as the Water Framework Directive (WFD) also defines the commitment of all Member States to the rational use and protection of water resources in accordance with the principle of sustainable development. As the key aim it was set out achieving "good status" for all surface water and groundwater by 2015 and in justified cases by 2021 or 2027.

4. POSSIBILITY OF STORAGE IN ROCK SALT DEPOSITS IN THE ZATOKA GDAŃSKA REGION

The possibility of storage of natural gas and compressed air in the Zatoka Gdańska region have been discussed in many articles and unpublished documentation [4, 10, 11]. The examples of selected location for the compressed air storage caverns are shown in Figure 1.

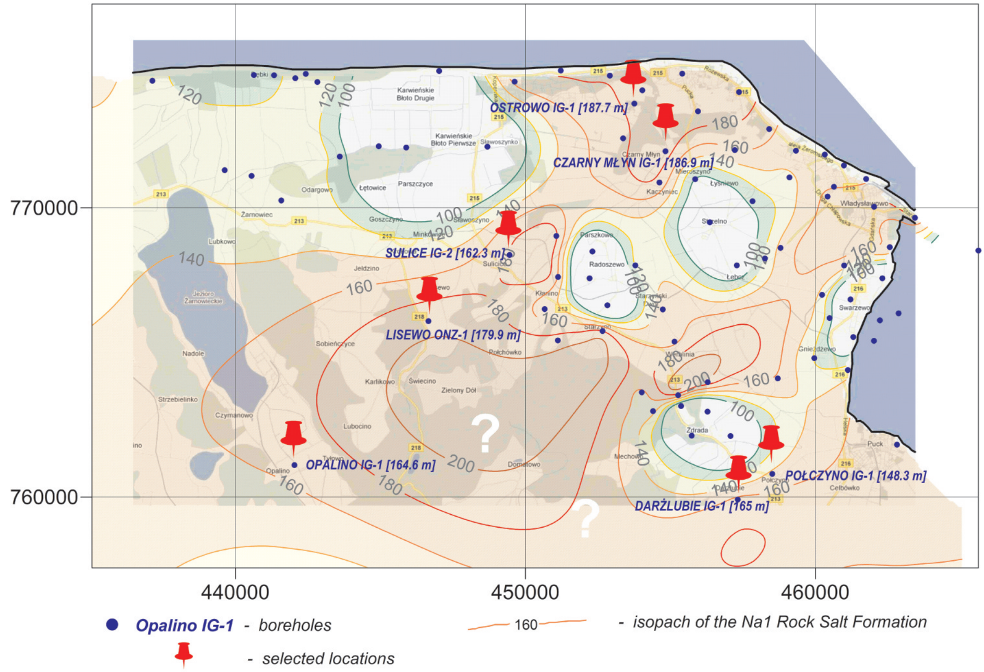

Fig. 1. The map of selected location for compressed air storage caverns in the Zatoka Gdańska region [11]

Below the most important conclusions and additional conditions on location of caverns in rock salt deposits resulting from ongoing work are presented.

4.1. The geological setting

The area of interest is located in the marginal zone of the East European Platform, on the north western slope of Peribaltic Syneclise. Within Zechstein formation the dominant rock is the Oldest Rock Salt (Na1). The top of the Na1 formation dips evenly to the SE from a depth of approximately 550 m below surface in Leba region to approx. 1300 m below surface in the region of Gdansk. The dip of the formation does not exceed 10°.

The thickness of the oldest rock salt varies from 0 to 225.7 m (Białogard IG-1) (Fig. 2). In the northern part of Zatoka Gdańska the thickness of Na1 formation reaches the highest values and in the southern part near Gdańsk the thickness of the formation does not exceed 50 m. In the Gdańsk region there also occurs the Younger Rock Salt formation (Na3). Its thickness amounts of approximately 10 m (Gdańsk II (Z-1)).

In the area of Zatoka Gdańska three rock salt deposits have been documented: Leba, Mechelinki and Zatoka Pucka. The geological structure of these deposits is similar and their total resources are estimated at over 21 billion tons [2].

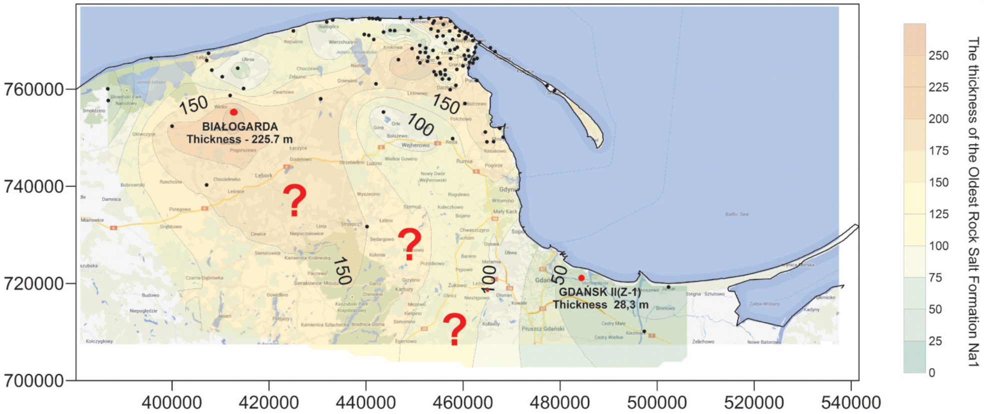

Fig. 2. The isopach map of the Oldest Rock Salt Formation (Na1)
in the Zatoka Gdańska region [10]

4.2. Storage capacity of caverns

Figure 3 presents the storage capacity of natural gas map developed by Ślizowski and Urbańczyk [11].

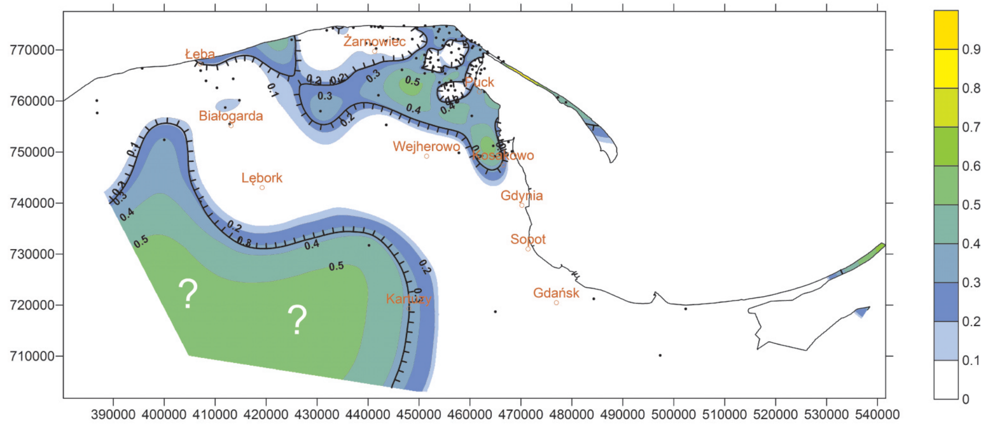

Fig. 3. The storage capacity map [Nm^3/km^2] after 15 years of storage
in the Zatoka Gdańska region [11]

The ongoing research indicates that obtaining such storage capacity for hydrogen will not be possible due to the tightness of caverns.

4.3. Surface conditions

In Figure 4 the potential level of environmental constraints in northern part of Zatoka Gdańska region is presented.

Comparing the potential level of environmental constraints with Figures 2 and 3 it can be seen that Na1 rock salt formation of the greatest thickness occur in zones of increased environmental constraints.

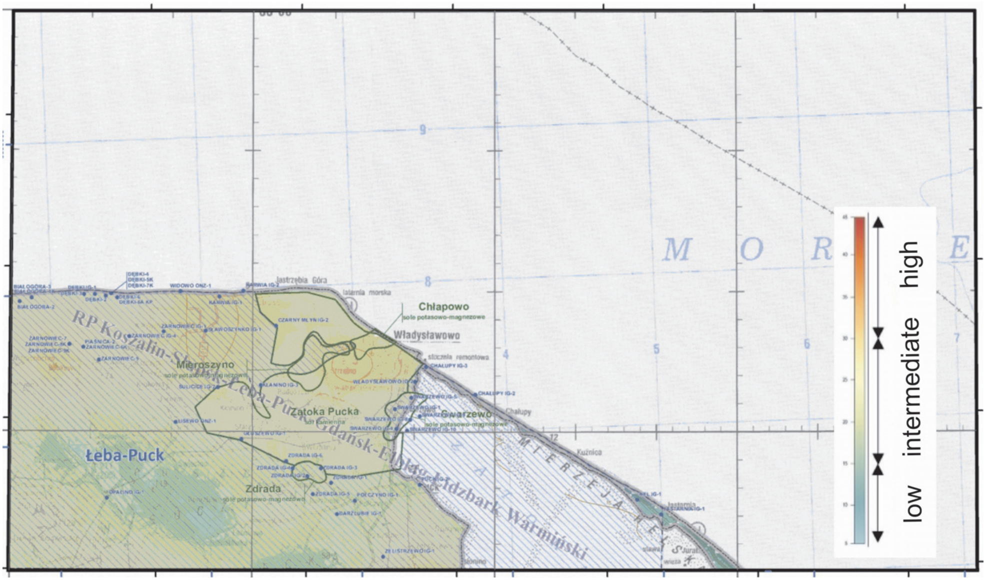

Fig. 4. The potential level of environmental constraints in northern part of Zatoka Gdańska region [3]

In the case of storage caverns leached in the area of interest the optimal solution of brine management is its discharge to the Zatoka Gdańska just as it is practiced in the case of the Kosakowo storage facility. Moreover the most preferred possibility of increasing storage capacity in this region would be the expansion of the existing storage facility in Kosakowo and use of existing diffusers. Such a solution most likely will not find the approval of the local community.

5. THE POSSIBILITY OF STORAGE IN THE GOLENIÓW SALT DOME

5.1. The geological setting

The salt dome Goleniów is a Zechstein salt structure which is breaking thorough the Triassic and Jurassic sediments. It is an asymmetric diapir with relatively regular walls, cut off from the southern side by the inverse fault zone [6].

Within the structure only one borehole was drilled (Goleniów IG-1). Also the extensive geophysical survey was carried out while prospecting the structure. The top of rock salt formation occurs at depth of 888 m below surface as it is shown on the Figure 5.

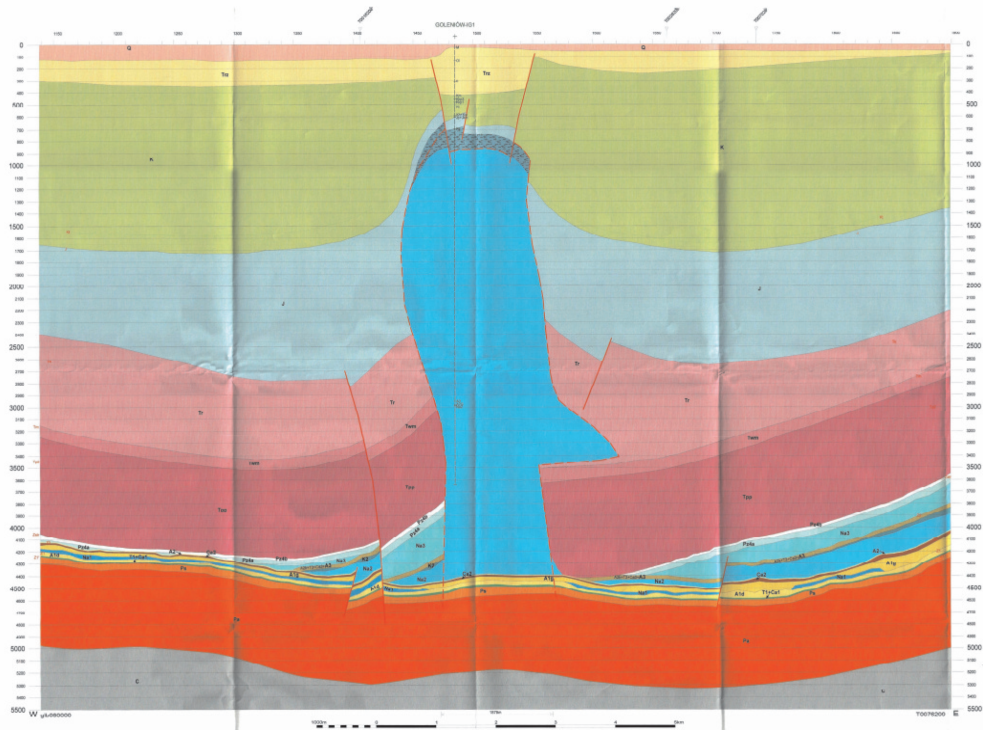

Fig. 5. The cross-section (W-E) of the Goleniów salt dome based on interpretation of T0076209 seismic profile [5]

5.2. Storage capacity of caverns

In the case of salt domes geological conditions are different than those for bedded formations and due to complicated geological structure even until the end of leaching process it is hard to predict the ultimate capacity of the cavern. The attempts of such assessment are presented in the article [11]. They concern Central Polish region domes and mathematical relationships presented there may not be appropriate for Goleniów dome.

5.3. Surface conditions

A large part of salt dome Goleniów is located in the area of low level environmental constraints what is shown in Figure 6. Only the north part of the structure is located in the region of slightly elevated level of environmental constraints. Almost 90% of the land in this region is covered by forests. Also protected environmentally protected areas are located outside the surface area covering the salt dome [3].

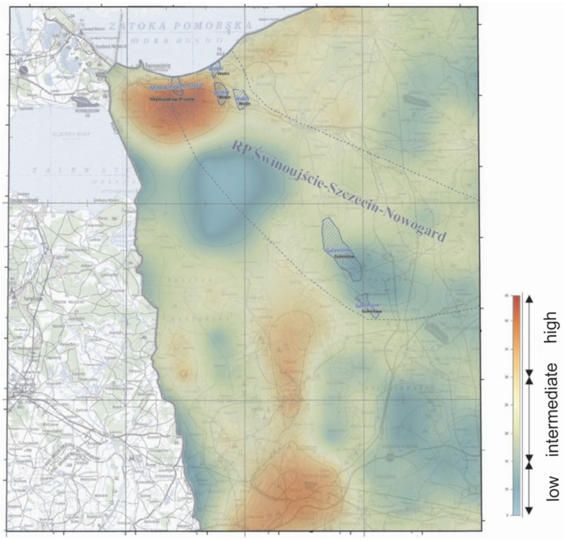

Fig. 6. The potential level of environmental constraints in vicinity of Goleniów salt dome [5]

5.4. Possibilities of brine discharging to underground structures

Near the Goleniów salt dome two anticlinal structures occur which could be adopted for potential discharge of brines derived from leaching caverns in Goleniów dome. These are Rokita Anticline and Trzebież Anticline. Much more perspective for brine discharge due to closer location seems to be the Rokita Anticline located about 10 km north-east of the Goleniów structure. Within anticlinal structure potential level for brine discharge could be lower Triassic sandstones with a thickness of approximately 200 m occurring at a depth of 1593 m below the surface. (borehole Rokita IG-1). Geological cross section of Rokita Anticline is shown in Figure 7.

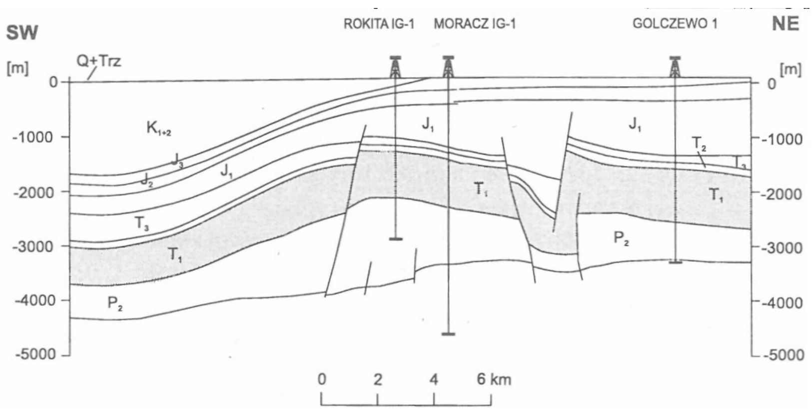

Fig. 7. Cross section of Rokita Anticline [13]

6. CONCLUSIONS

Of the three analyzed substances, the simplest and providing the most comprehensive possibilities of usage in energy industry is storage of natural gas.

The natural gas could be stored both as a strategic reserve and as a reserve for seasonal and daily peak demand. Also its calorific value is highest among analyzed gases. The possibility of production of natural gas from surplus energy is rather not expected. This can be achieved in case of hydrogen (for covering seasonal demand) and compressed air (for covering daily demand).

Both the climatic (wind strength) and geological conditions for storing surplus energy in the region of Polish coast are beneficial. Taking this opportunity to storage surplus energy could have economic significance especially in the case of withdrawal plans of a nuclear power plant construction in this area. Excessive optimism which can be found in some publications is however unjustified and construction of appropriate infrastructure requires to solve many technological, ecological, formal and legal issues particularly in case of hydrogen storage. First (as in the case of nuclear power plants and underground storage) Gminas should be found in which the local community's acceptance for construction of storage facility could be obtained. It seems that construction of coupled storage facility for hydrogen and natural gas could easier gain acceptance than the storage facility only for hydrogen.

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