RESEARCH ACTIVITY IN AIR AND OTHER GASES COMPRESSION AND ENERGY STORAGE

ACTIVITATE DE CERCETARE ÎN COMPRIMAREA AERULUI ŞI A ALTOR GAZE ŞI STOCAREA DE ENERGIE

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Abstract: *COMOTI and its industrial partners have developed collaborative activities on the energy storage possibilities of air, and also on another gases like methane, carbon dioxide, and also hydrogen in exploited and preserved salt caverns, with storage capacities between 50,000 and 500,000 m*^{3}*. In applications, research in the energy sector needs partnerships with the energy industry and university medium. The issue of energy storage concerns both the decision-makers and the universities, constituting an important chapter in the energy strategies of the energy producing countries and, implicitly, to increase the Romanian energy security.*

Keywords: compression, energy storage, air, carbon dioxide, methane, hydrogen.

Rezumat: *COMOTI și partenerii săi industriali au dezvoltat activități de colaborare cu privire la posibilitățile de stocare a energiei aerului, precum și a altor gaze precum metanul, dioxidul de carbon și, de asemenea, hidrogenul în cavernele de sare exploatate și conservate, cu capacități de stocare între 50.000 și 500.000m*$_3$*. În aplicaţii, cercetarea în sectorul energetic necesită parteneriate cu industria energetică şi de asemenea cu mediul universitar. Problema stocării de energie privește atât factorii de decizie, cât și mediile universitare, constituind un capitol important în strategiile energetice ale țărilor producătoare de energie și, implicit, în creșterea securității energetice a României.*

Cuvinte cheie: comprimare, stocare energie, aer, dioxid de carbon, metan, hidrogen

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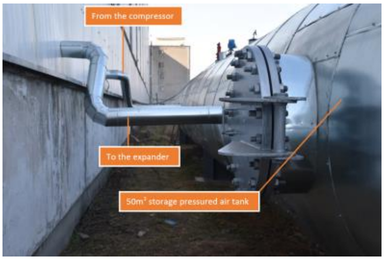
1. Introduction

COMOTI - Romanian Research & Development Institute for GAS TURBINES, has directions in development of screw compressor and expanders, in the participation in national and international programs, in technical-scientific partnership, in the production under conditions of high efficiency of the electrical and thermal energy, in the ecological, rational and efficient exploitation of the resources. natural technologies, new technologies and equipment, designed for environmental protection and environmental protection. COMOTI did participate in a competition in the Operational Competitiveness Program (POC) organized by the National Authority for Scientific Research and Innovation on behalf of the Ministry of European Funds (MFE) with a project dedicated to solve the energy storage, called: "Innovative energy storage technology in the CAES system through the use of screw oil injected compressors and expanders. Acronyme: ROCAES". The storage medium of the compressed air is a pressure vessel of about $50m^3$, at 21 bara, see figure 1 below. At hourly intervals when the demand for electricity is high and the price of energy is higher, the "screw expander" equipment starts. The demonstration model of the energy storage station is mounted at the Popeci Enterprise, Craiova, Romania.



a. Compressor and expander unit + heat recover tank   b. $50m^3$ storage pressured 25bar air tank

Figure 1, a, b. ROCAES assembly at the Popeci-Craiova, using a 50 m^3 air pressured tank. [1]

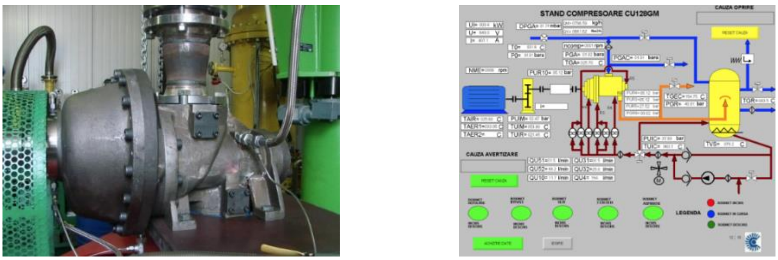
Due to collaboration with University of Petroşani, COMOTI start the developing of the storage projects in depleted gas deposits or in depleted or conserved coal or salt mines. The activities of the Research Laboratories of the Petroşani University, are aimed at developing topics with fundamental and applicative impact, in integrative, multidisciplinary and interdisciplinary approaches, in accordance with the priority issues at regional, national and international level, which will ensure the increase of visibility and competitiveness.

2. COMOTI screw compressor families

The accumulated experience in the field of high-speed blade machines has allowed, in its own design, the creation of families of centrifugal air and natural gas compressors and centrifugal air electro-blowers, in a wide range of flow rates and pressures, COMOTI has become the only national manufacturer for such complex equipment. In the field of screw compressors, COMOTI cooperates with GHH - RAND Germany - part of the INGERSOLL - RAND group in the USA, in the development of screw compressors for natural gas and of the groups that include such compressors sold in large numbers in the country, as well as for export: USA, Germany, Poland, Canada, Russian Federation, etc. COMOTI has developed families of own natural gas compression units in collaboration with City University London and the German company Jaecklin GmbH.

Feedback from potential customers necessarily imposed the design of a screw compressors family, products able to develop in the first instance discharge pressures of 45 bara, at flows at about 1000Nm^3, figure 2 [2] and flows about 5,000 Nm^3/h, figure 3 [3], following in the next stage, COMOTI developed product that achieve discharge pressures of 75 bara, specially created for pumping CO_2 trought pipes in supercritical regime. COMOTI Institute's experience in design and execution of compression equipment has created conditions for a new product, an unit compressor, able to provide the following:

-suction pressure: 5 bara;
-discharge pressure: 45 bara;
-flow: arround 1,000 Nm^3/h.



a. CU128GM compressor unit on the INCDT COMOTI test bench

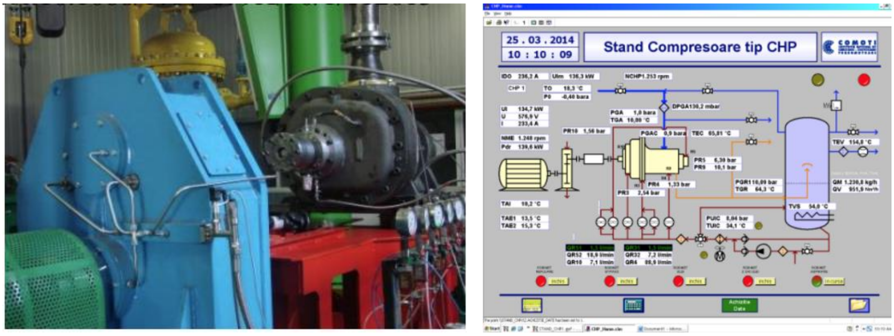
b. Print screen generated by the data acquisition system

Figure 2. CU128GM unit compressor for 1,000 Nm^3/h @ 45bara[7]

As a crowning effort of design, the final product was tested with good results on the air test stand of the Institute. In partnership with City University from London and GHH-Rand Company Germany, COMOTI approached the production of a screw compressor with oil injection type, having following operating parameters:

- suction pressure: 4.5 bara;
- discharge pressure: 45 bara;
- flow displaced: 5,000 Nm3/h;
- gas pumped: gas.

[7] http://www.comoti.ro/en/Compresoare-cu-surub.htm



a. CHP220 compressor unit on the INCDT COMOTI test bench

b. Print screen generated by the data acquisition system

Figure 3. CHP 220-unit compressor for 5000 Nm^3/h @ 45bara[8]

COMOTI together with Ingersoll Rand (GHH Rand), on the basis of a license, produces and supplies the compressors with screw type CU (CU64, CU90, CU128) and CR (CR90 G and CR200GK). COMOTI has been cooperating with GHH company since 1999 in the development of natural gas, air, CO_2 or N_2 compression plants using the various solutions of COMOTI compression units, under the GHH license. The minimum and maximum pressures of the compressor families CU64, CU90 and CU128 are constant, these being: min. 6 bara and maximum 26 bara. The characteristics are relatively similar, differing in the power consumed and the flow of gas conveyed, depending on their constructive size. Minimum and maximum gas inlet temperatures are: (-60°C) -40°C to 50°C. The maximum exhaust temperature is 120°C. The compressor CU128G is currently being used in an energy storage facility, during a research project, completed in March 2020, see the introduction. The compressor is driven by a 100kW electric motor, if the fluid compressed is air, and for other gases like CO_2, CH_4, H_2, will be necessary to replace the existing motor with another power asynchronous electric motor, to reach the parameters imposed by the calculations.

A screw expander was developed for converting the energy of compressed gas into green electricity. This unique group operates using an oil injection screw compressor. The thermodynamic cycle of an injection screw compressor that is a volumetric machine with positive displacement is also currently studied [4] and is used in refrigeration and air conditioning, but also in power generation. COMOTI's Expander Helical-Generator system is an expander in oil-injected turbine configuration (advantageous solution for relatively small flows) that has the advantages of high efficiency due to near-isothermal compression, low maintenance costs due to its very good reliability, few pieces in motion [5], see the figure 4 below at COMOTI test bench and also the figure 1, a, above, installed at Popeci, Craiova

[8] ibidem

conty, Romania. Compressed air from the storage tank is released into the expander, this one entering automatically in generator regime above the synchronous speed of 1470 rpm and injecting electric power into the grid.

Figure 4. The expander unit on the test bench at COMOTI[9]

In the subsequent figure, the generated power at the first experimental start-up is presented, for commissioning period. The positive power shows that the asynchronous electric machine is launched as motor, absorbing power from the grid. Then, as the expander inlet valve gradually opens to suction air from the reservoir, the electric machine is spun over its synchronous speed as generator. It has a normal instantaneous spike of almost 40 kW generated power when reaching synchronous speed, and then it begins to stabilize in generator regime, injecting almoust 80 kW maximum electric power.

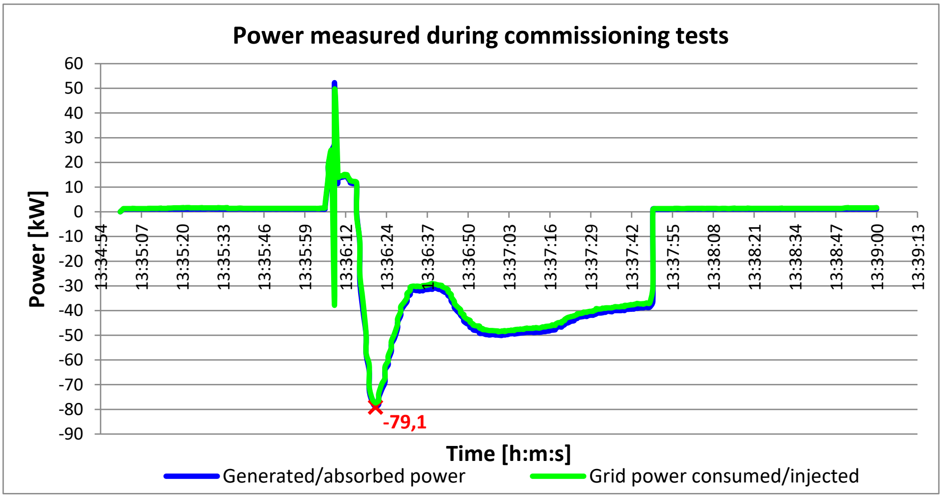


Figure 1. Power plot relying on acquired data during commissioning test [1]

[9] http://www.comoti.ro/ro/Proiect_ROCAES.htm?pag=3

The two power curves in Figure 5 are very close, but the injected power into the grid is slightly lower because electric consumers in the electric cabinets also need to be supplied with the power produced.

3. Results and energetic calculations

The CAES project closed in March 2020, consists of a 100kW twin-screw compressor that supplies compressed air into a reservoir, and a 132kW twin-screw expander. The compressor is driven by a 110kW asynchronous three-phase motor. The expander is driven by the compressed air released from the 50m^3 reservoir, spinning a 132kW asynchronous three-phase generator, see the figure 6. The system's operation has been explained in detail in our previous paper[10] [5].

At hourly intervals, when the demand for electricity increases and hence the energy price is higher, the screw expander driving the electric generator starts its operation. The air compression is accompanied by an important energy loss due to the heating of the compressed air in the compression process. The heat of the cooling oil is partially recovered by the 5m^3 water buffer tank, that stores the thermal energy of the oil, and transfers it to the oil heating the expander, since air expansion is accompanied by a severe temperature drop. In the current configuration, with a 50 m^3 air reservoir, it is estimated that the compressor will be able to operate around 4 hours per day, and the expander about 30 minutes, in case of peak electricity demand.

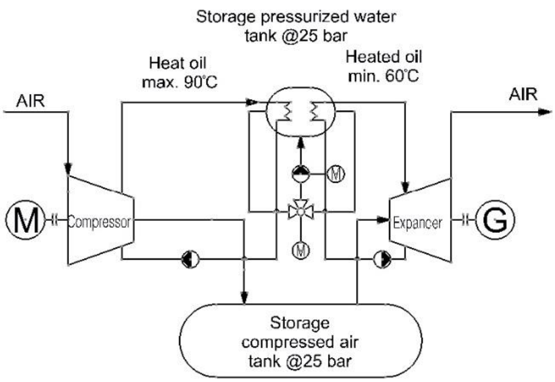


Figure 6. CAES block diagram

The expander operates with 10 bar (abs) suction pressure, since the maximum pressure of the tank is 12 bar (abs), at an air flow of:

$$M_{air,exp} = 1360 \left[\frac{m^3}{h}\right] = 0.39 \left[\frac{kg}{s}\right] \text{ at } 20°\text{C and } 60\% \text{ rel. humidity} \quad (1)$$

[10] http://www.comoti.ro/ro/Proiect_ROCAES.htm?pag=3

If we keep the same expansion ratio, with p_{in} = 21 bar (abs) and p_{out} = 4.5 bar (abs), we will have:

$$\pi_{exp} = \frac{p_{in,abs}}{p_{out,abs}} = 4.67\ [\text{-}] \tag{2}$$

The output pressure p_{out}, for an input pressure p_{in} of 10 bar (abs), will be:

$$p_{out} = \frac{p_{in}}{\pi_{exp}} = 2.14\ [bar, abs] \tag{3}$$

When working with a normal oil injected compressor, it is supposed that the exit temperature from the compressor to be around 90°C. Because the storage compressed air tank is losing temperature with about 1°C/h, T_{in} in the expander after 20 hours will be about 70°C = 373.15K, and c_p=1004.8 J/kg/K. The total work of the expander is given by the following equation:

$$L_{exp} = c_p \cdot T_{asp} \cdot \left[\pi_{exp}^{\frac{k-1}{k}} - 1\right] = 190756.0\ \left[\frac{J}{kg}\right] \tag{4}$$

Thus, the isentropic power rate of the expander will be:

$$P_{exp,is} = L_{exp} \cdot \frac{M_{air,exp}}{1000} = 74.2\ [kW] \tag{5}$$

If we introduce the efficiency of the expander assembly, $\eta_{is} = 0.75$, the real power rate of the expander will be:

$$P_{exp,real} = P_{exp,is} \cdot \eta_{is} = 55.65\ [kW] \tag{6}$$

Like a conclusion, in our experiments, was achieved a peak of 79 kW power rate, but a medium of 40 kW power rate. The errors are in the domain of 28.5…29.5%, and that is correct because have been not taken into consideration the energy saved in the water buffer tank, see the figure 6.

3. The using of the salt cavern for long therm energy storage

Our project was for energy storage in a form of compressed air, for wind and solar farms, as renewable generation is already less expensive per unit than its polluting counterparts. If storage is available at sufficiently low cost and high performance, renewable energy would rapidly displace all other generation forms, and it is a versatille sollution for batteries solution energy storage[11].

[11] https://phys.org/news/2018-10-solar-energy-compressed-air.html

In the table 1 bellow are shown the closed wells S251, S254 and S268, from Târgu Ocna county, Romania, suitable for storage of air, CH_4, CO_2 or even H_2, in conformity with the romanian law[12].

Table 1. Closed wells in the "Târgu-Ocna - county"

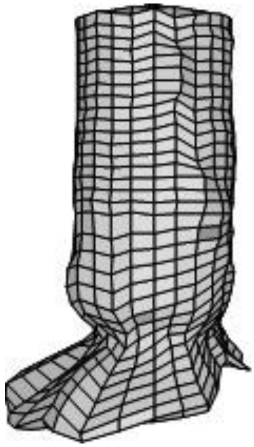
Well no.	Elevation variation [mm]	Period [years]	Volumul of the cavern [m^3]	Diameter [m]	Wells for CO2 storage (Yes/No)
S254	0	150	580714,88	178	Yes
S255	-13,60	36,74	351193,25	91,6	
S256	+1,02	156			
S282	-14,10	35	105416,82	44,6	
S251	+1,10	454			Yes
S270	-8,70	57,44			
S259	-5,6	89,2			
S268	+2,7 ÷ 4,9	∞			Yes

The wells S254, S251 are not in populated area and these two well of 200,000 m^3, and 580,714.88 m^3, can be used for the experiments and for the storage for long term of the air, CO_2, H_2, or methane. For air, the capacity of 200,000 m^3 salt cavern means at 20°C and 20 bar, and 60% humidity, a density of 23.76 kg/m^3, [13], and about a total of 4,752,000 kg of air (aprox. 5000 tones). At a rate of 0.39 kg/s for expander functioning, from the calculations, the pressure in the salt cavern decrease with just 0.233 Pa. For a functioning of the expander from 21 bara to 12 bara, we have to decrease the pressure about 9 bar = $9 \cdot 10^5\ Pa$, that means 44.7 days for 70kW continuous electricity production. Of course, the calculation is not for a real enterprise necessity, because the energy consumed is much greater than 70kW rate of energy. The total energy stored is about 75.000kWh, and for a turboexpander of 10MW for example, the energy stored can assure a total of 7.5 hours for continuous functioning.

The closed salt cavern S254 with a capacity of 580,714.88 m^3, is shown in the figure 8 below. The energy estimated for that mine capacity at 20 barg storage pressure, is about 220MWh, enough energy stored for a wind farm or solar farm, for example the wind farm from CEZ company installed turbines in Constanta district, Romania[14].

[12] http://www.namr.ro/co2-law/procedures-instructions-co2/
[13] https://www.omnicalculator.com/physics/air-density
[14] https://www.cez.ro/en/about-us/energy-generation/wind-energy-generation/about-the-activity.html

a. Picture from the conserved well 3D model given from the well calliper



b.3D model given from the well

Figure 8. Salt cavern S254 in Târgu Ocna county, Romania

With the software FLAC 3D[15] for geotechnical analyses of soil, rock, groundwater, constructs, and ground support, will be analysed the displacements and the strains in salt mine rocks, and others, because an imposed initial pressure of 20 barg, for an initial study. Dissolved salt and mined hard rock caverns are also being examined for this potential application. Pressure, temperature, and humidity may have detrimental impacts on the salin walls. An impermeable caprock and some form of structural trap are required to contain the air/CO_2/H_2.

6. Conclusions

In Romania, as a result of the introduction of specific legislation that strongly stimulates investments in energy storage directions, the capacity of wind power plants and farms with photovoltaic panels will increase very rapidly. Thus, the need arises to store some of the energy produced during peak operating periods and to use it during peak consumption times. The creation of energy storage stations for the subsequent generation of electricity has the following main roles:

-reduces the costs of electricity by storing the energy obtained outside peak hours, when its price is lower, to be delivered during peak hours at higher prices.

-in order to improve the reliability of energy supply, energy storage systems support users when power grid failures occur due to natural disasters, for example.

-the third main role is to maintain and improve the quality of electricity, frequency and voltage.

[15] http://www.itascacg.com/software/FLAC3D

COMOTI created a demonstration model of a storage station, with the acronym ROCAES that is a relatively small energy storage station, the maximum power generated at the shaft being of a max. 132 KVA. However, the availability of the station is limited by the small volume of the storage vessel which involves high costs and which at this stage of project development is not justified, the aim of the project being to demonstrate the feasibility of the storage solution in the CAES system. For a larger design station, INCDT COMOTI plans to implement the solution with the storage medium of the compressed air, methane, carbon dioxide and also hydrogen in salt mines. COMOTI in colaboration with private companies and also with the aid of the other research centers, like University of Petroşani, Politehnical University of Bucharest, National Research and Development Institute for Cryogenic and Isotopic Technologies, National Agency for Mineral Resources, the National Salt Company S.A. and so on, with European and Norvegian founds, is determined to participate in solving the major emerging market needs for EES (Electrical energy storage) with a key technology: to use more energy from renewable sources and less fossil fuel and in the future to develop a smart grid.

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[10] http://fossil.energy.gov/programs/fuels/hydrogen/Hydrogen_Delivery_R%26D.html

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