

The Calimanesti-Caciulata Spa, Romania

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ABSTRACT

The paper briefly presents the therapeutic effects of the cold, shallow thermo-mineral, and deep thermo-mineral waters from the Calimanesti-Caciulata spa in Romania.

The aquifers in the area are presented in larger detail, mainly the geothermal reservoir, including some results of a computer simulation for long-term production.

The final part of the paper presents the outcome of a project carried out in 2001-2002, with partial financial support obtained from the European Commission in the INCO – COPERNICUS program, for the design and completion of a heating system using geothermal water and the combustible gases separated from it.

1. INTRODUCTION

The Calimanesti-Caciulata spa is located at the southern limit of the Southern Carpathians, at the downstream end of the Olt river defile, between the Vinturarita calcareous massif in the western part and the Olt river's left bank in the eastern part (Figure 4), on the E15 A highway, 18 km north of Ramnicu Valcea and 18 km south of Sibiu. The Calimanesti-Caciulata spa has 2,500 beds in 1 to 3 stars hotels (of which Hotel Cozia has its own treatments facility), and 570 beds in 1 to 4 stars villas. The Institute of Physical Medicine, Balneology and Medical Recovery, of the "Carol Davilla" Medicine and Pharmacy University of Bucharest has a clinic in the Calimanesti-Caciulata spa.

2. THERAPEUTIC EFFECTS OF THE MINERAL AND THERMO-MINERAL WATERS

The mineral water springs from this area are first mentioned in the chronicles of the Roman campaigns, and by the middle of the 19th Century these waters were bottled and sold in France, being similar to the waters of some French spas (Chapelle, Eaux Bonnes, and Chatelguyon).

The cold mineral waters (8-10°C) from the 12 natural springs in the area contain sulphate, chlorine, sodium, iodine, brome, calcium, etc., and are used in internal cures for the treatment of kidney diseases (nephritis and pielitis, having diuretic and anti-inflammatory effects), liver, bile bladder, and stomach diseases (stimulates the gastric and bile secretions, favours the glycogen retention in the liver). These waters also have an anti-allergic effect and decrease the pathologically high glycaemia.

The shallow thermo-mineral waters (produced by 9 shallow wells) are of the sulphate-sodium-chlorine-brome-iodine type, with calcium, having a TDS up to 18 g/l.

The deep thermo-mineral waters (produced by 3 wells about 2,500 m deep) are of the sodium-chlorine type, with

calcium and iodine, having a TDS of about 2 g/l. These waters are used in external cures for the treatment of stabilised inflammatory rheumatism, degenerative rheumatism (arthrosis, spondilosis), degenerative articulation diseases of elder people, peripheral neural diseases (neuralgia, neuritis, etc.), chronic gynaecologic diseases, and (by inhalation) for the treatment of some respiratory system diseases (rhino-pharyngitis, chronic sinusitis, chronic bronchitis, bronchic asthma).

3. THE GEOTHERMAL RESERVOIR

The crystalline rocks are assigned to two overthrust nappes: the Getic Nappe and Overgetic Nappe, being represented by two complexes belonging to the Sebes-Lotru series the paragneisses complex that is situated in the lower part and the paragneisses with amphibole's complex, in the upper part of the series. The Overgetic Nappe crystalline is represented by the Cozia gneiss's complex that belongs to the Cumpana-Cozia series (Figure 1).

The sedimentary formations include the deposits overthrust by the Getic Nappe, Overgetic Nappe and the sedimentary deposits formed after these two overthrust. Previous geological and hydrogeological research assumed that the thermo-mineral water is mixed into sedimentary deposits located above overgetic crystalline rocks (the Cumpana-Cozia series), but the deep geothermal wells 1006 and 1008 evidenced a thickness of these sediments exceeding 3,260 m. The overlap of the sedimentary deposits overthrust by Overgetic Nappe above Getic Nappe sedimentary deposits could be the key of this considerable thickness. This observation allowed to infer that carbonate rocks of the Vinturarita calcareous massif continue at the base of the sedimentary deposits supplying the thermo-mineral waters.

Two significant hydro-geological cross sections through the Calimanesti-Caciulata reservoir are given in Figure 2. The interpretation of available hydrogeological parameters lead to the conclusion that a complex mixing process of three water types in different proportions combined with a redox process determines the main chemical and physical properties of the thermal and mineral reservoir waters (Mitrofan et al., 1993; Slavoaca et al., 1991; Blaga, 1977). The three water types are:

- thermal karstic water (meteoric waters from karstic massifs which cover a large intake area) which supplies the underground water reservoir from depth;
- mineral and thermal water, chemically similar to brine linked to oil reservoirs, illustrated by the dominant methane content of the solution gas phase;
- locally infiltrated waters from the Olt river.

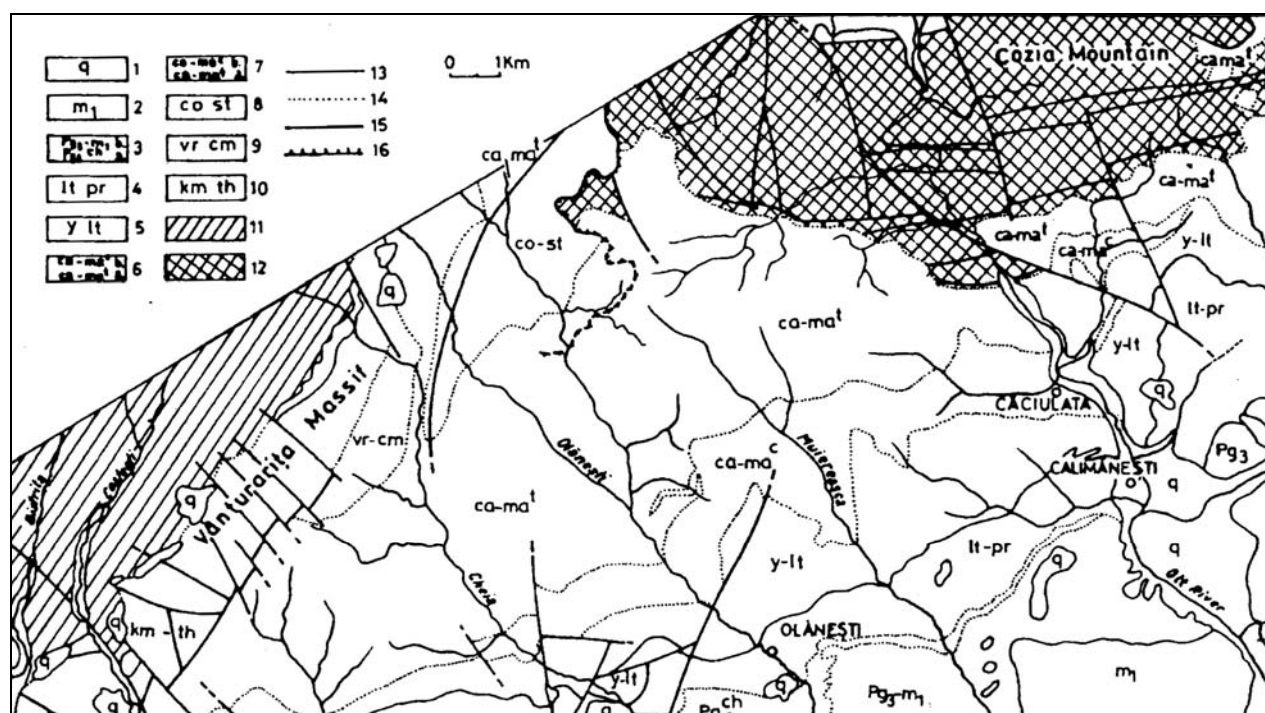


Figure 1: - Geological map of the Vanturarita - Calimanesti area

Legend: Quaternary (q): 1 - sands, gravel with marls intercalation; *Lower Miocene* (m_1): 2 - Muereasca Sandstones; *Lower Miocene - Oligocene*: 3a. Pucioasa Marls ($Pg_3 + m$), 3b. Cheia Conglomerates (Pg_3^{ch}); *Eocene*: 4 - Olănești Marls (lt - pr), 5 - Calimanesti Conglomerates (y - lt); *Getic Nappe*, Upper Cretaceous: 6a. Turnu Sandstone (ca - ma^1), 6b. Căciulata Series (ca - ma^c); 8 - gritty, conglomerates, carbonate deposits and quasitlyschy gritty deposits; 9 - marls and clays with sandstone intercalations and polymictic conglomerates (co -st); *Jurassic*: 10 - breccious limestones; *Upper Proterozoic*: 11 - Sebes - Lotru crystalline series; *Overgetic Nappe*, Upper Cretaceous: 7a. Turnu Sandstone (ca - ma^1), 7b. Căciulata Series (ca - ma^c); *Upper Proterozoic*: 12 - Cumpăna - Cozia crystalline serie; 13 - geological boundary; 14 - lithological boundary; 15 - fault; 16 - overthrust boundary.

The presence of hydrogen sulphide is related to reduction reactions generated by anaerobic sulphate reducing bacteria (*Desulfovibrio Desulfuricans*, *D. Gigas*, *D. Africanus*) developing in organic matter. Presence of methane and ammonium like, free and dissolved gases, C_2H_6 , C_3H_8 , C_4H_{10} and dissolved chemical compounds as HCO_3 , Fe, Mn, are strong arguments in favour of main redox reactions.

The mixing between mineral and thermal waters with compounds resembling petroleum reservoir brines was proved by Golita, 1974. The most important argument was the chemical similarity between the mineral water from Calimanesti-Căciulata and the water from oil well 614-Bunesti (about 40 km south-west).

Locally infiltrated (meteoric and stream) waters flow through Senonian and Eocene deposits. Piezometric head distributions allowed mixing with local infiltration waters only at shallow levels. Mixing at greater depths may be possible only by aquifers that are supplied at high elevations. Local infiltration waters are responsible for the cooling of the thermomineral waters. The geological map shows that the infiltration intake area is more important in the southern part and less important in the northern part (Bivolari zone) where occurrence of thermal waters has been reported since Roman times.

In order to estimate the reservoir parameters, in October 2000, a relevant well test, using a slick line / quartz memory gauge, has been carried out for well 1006 Căciulata (which was selected for the INCO-COPERNICUS project). The well 1006 Căciulata was drilled in 1982 to a final depth of 3,250 m. The well is completed with a 7" casing from top to 2,399 m. The inflow of geothermal water in the well is via open hole between 2,499 – 3,250 m. The well is equipped with a 3½" production tubing from surface down to 2,266 m.

The test consisted of recording pressure and temperature profiles under dynamic and static conditions and also bottom hole pressure transients i.e. buildup for 14 hours and draw down for 23 hours. Processing of downhole pressure drawdown and buildup sequences, at an average 40 m³/h self flowing discharge rate, led to the following reservoir / well interface parameters:

- permeability thickness (kh) = 3,500 mD·m
- skin factor (s) = 20

Those evidence a low permeability reservoir and a poorly developed well which would definitely require, in the perspective of a significantly increased production via artificial lift instead of the present self flowing mode, alongside well stimulation by acid spotting.

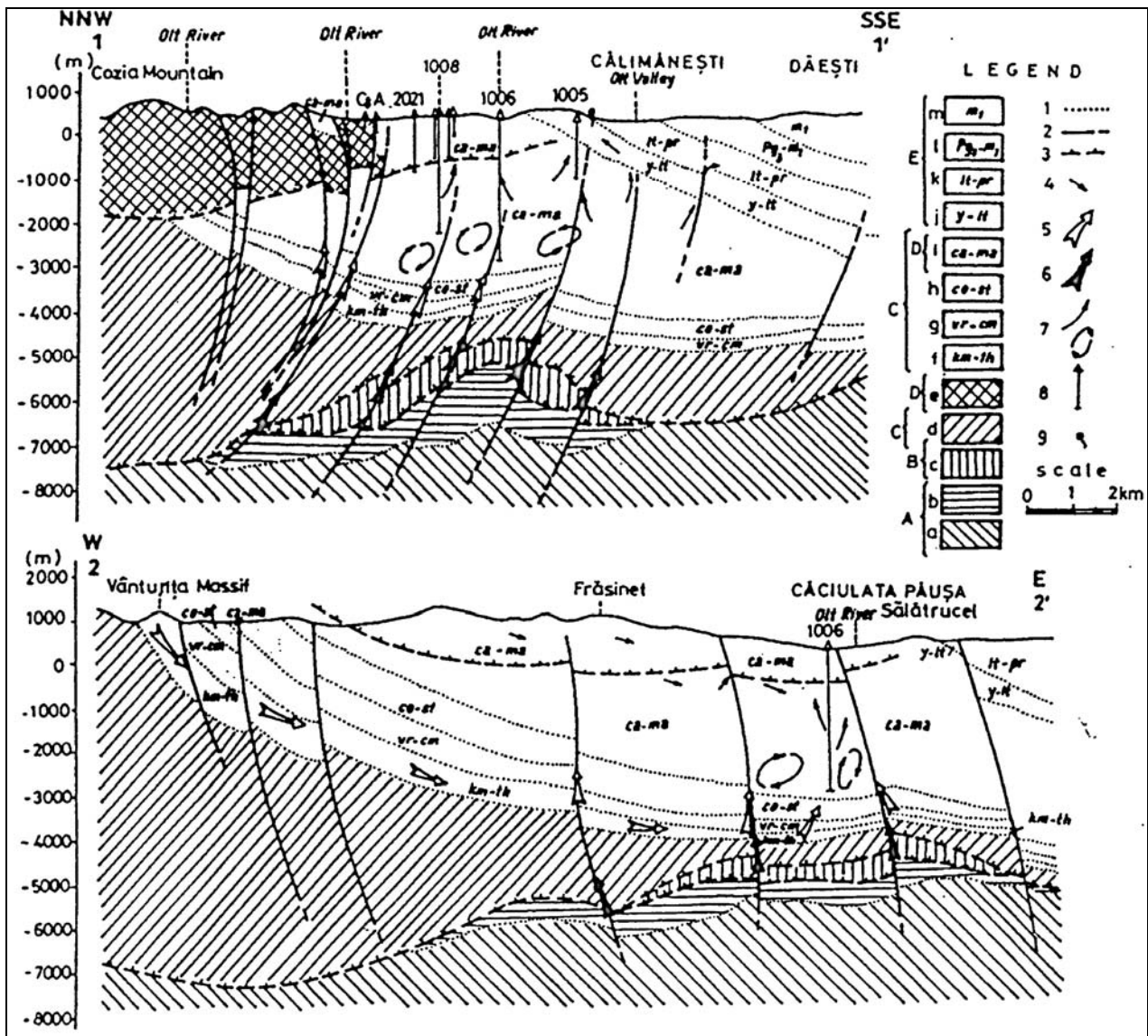


Figure 2: - Hydro-geological cross section

Legend: A - Danubian Domain: a - crystalline basement; b – sedimentary formations; B - Severin Nappe; C - Getic Nappe; d - crystalline rocks (Sebes - Lotru series); f – breccious limestones; g - marls and clays with sandstone intercalation and polymictic conglomerates; h – gritty conglomerate, carbonate deposits and quasiflysch gritty deposits; i - gritty deposits (Turnu Sandstone) and marls, sandy clays with sandstone intercalation (Căciulata Series) D - Overgetic Nappe; e - crystalline rocks (Cumpana - Cozia Series); I - gritty deposits (Turnu Sandstone) and marls, sandyclays with sandstone intercalations (Căciulata Series); E - Sedimentary formations formed after getic and overgetic overthrusts; j - conglomerates, sands and breccias (Calimanesti Conglomerate Series), k - Olanesti Marls Series; l - conglomerates, sandstones, clays (Cheia Conglomerates) and black clays, marls, sands (Pucioasa Marls); m – sandstones with marls intercalation (Muierasca Sandstones); 1 - fault; 2 - overthrust boundary; 3 - waters of infiltration proceeded from local precipitation; 4 - karstic water inflow; 5 - mineral water inflow similar brine; 6 - water of the thermomineral reservoir; 7 - water wells; 8 - mineral spring.

Miklos Antics carried out a computer simulation of the Calimanesti-Căciulata reservoir, in order to estimate its behaviour during a long-term exploitation. The computer code TOUGH2 PC Version, developed by Karsten Pruess at the Earth Science Division, Lawrence Berkeley Laboratory, University of California, was employed for the simulation of the geothermal reservoir. Based on the available geological information, a three dimensional multi-layered model consisting of six stacked layers has been set up. The governing assumptions on which the simulation runs have been based on are:

- The layers are horizontal;
- The reservoir is homogeneous in lateral extent with constant layer thickness;
- The fluid in the reservoir is pure water.

A variable size, squared meshes, grid was selected for the horizontal discretisation. In order to better calibrate the model from available data for well 1006, a radial grid with variable permeability was set up around the well. The boundary conditions were assigned according to the hydro-

geological model of the area i.e. vertical inflow from North to South, and lateral inflow from the Olt valley. Considering the fractured nature of the reservoir the grid space assigned to layer AD has been post processed with the MINC (Multiple Interacting Continua) feature of the simulator taking into account that (i) fractures occupy 5% of the unit volume of the rock, (ii) fractures are spaced in three directions at 50 m and (iii) local flow occurs between the fracture and the matrix space. Furthermore, the matrix space was assigned a porosity of 1% and a permeability of 0.1 mD (Ungemach et al., 2002).

The natural state conditions of the reservoir were simulated by allocating to the bottom layer a heat source with a unit flux of 80 mW/m². The simulation was run for a long period of time, 2.3 million years (corresponding to the development of the reservoir over geologic time), until steady state conditions were reached.

Since there were no production history data available, the model was calibrated on the data provided by the transient pressure tests. There were three models considered: one analytical and two numerical respectively. The analytical model is a double porosity slab model with infinite boundary and changing wellbore storage. The changing wellbore storage was introduced due to the two-phase flow regime that occurs in the wellbore.

Based on the calibrated model, a long-term production simulation was run for 20 years, considering the seasonal variation of the production flow rates: 11 kg/s in winter (7 months/year), and 6 kg/s in summer (5 months/year), i.e. a yearly average discharge of about 9 kg/s. It can be observed from Figure 3 that in the future the reservoir behaviour will be very stable, an average 14 bar drawdown being noticed at the end of the last winter period. However,

in the meantime the well will recover during the summer production period.

4. ENERGY SUPPLY AND DEMAND APPRAISAL

The well 1006 can produce in artesian discharge up to 16 l/s geothermal water with a wellhead temperature up to 96°C. The geothermal water from well 1006 has a TDS of 18.62 g/l, the main components being chlorine (9.2 g/l), sodium (3.1 g/l), and calcium (2.0 g/l), other components being potassium, phosphate, sulphate, silica, bicarbonate, magnesium, aluminium, and iron.

The gas water ratio for a 6 l/s water production flow rate was determined at 2.2 m³_N/m³, with an average moisture content of 0.4 kg/m³_N. The composition of the gases separated from the geothermal fluid produced by well 1006 is given in Table 1. Based on these data, the lower heating value of the separated combustible gases was calculated to be $H_i = 28,801 \text{ kJ/m}^3_{\text{N}}$.

Table 1: Composition of the associated combustible gas phase

Gas component	Value [%]
CH ₄	79.54
C ₂ H ₆	0.2588
C ₃ H ₈	0.1188
i-C ₄ H ₁₀	0.0146
n-C ₄ H ₁₀	0.0202
i-C ₅ H ₁₂	0.0037
n-C ₅ H ₁₂	0.0022
C ₆ H ₁₄	0.0003
N ₂	14.70
CO ₂	1.04

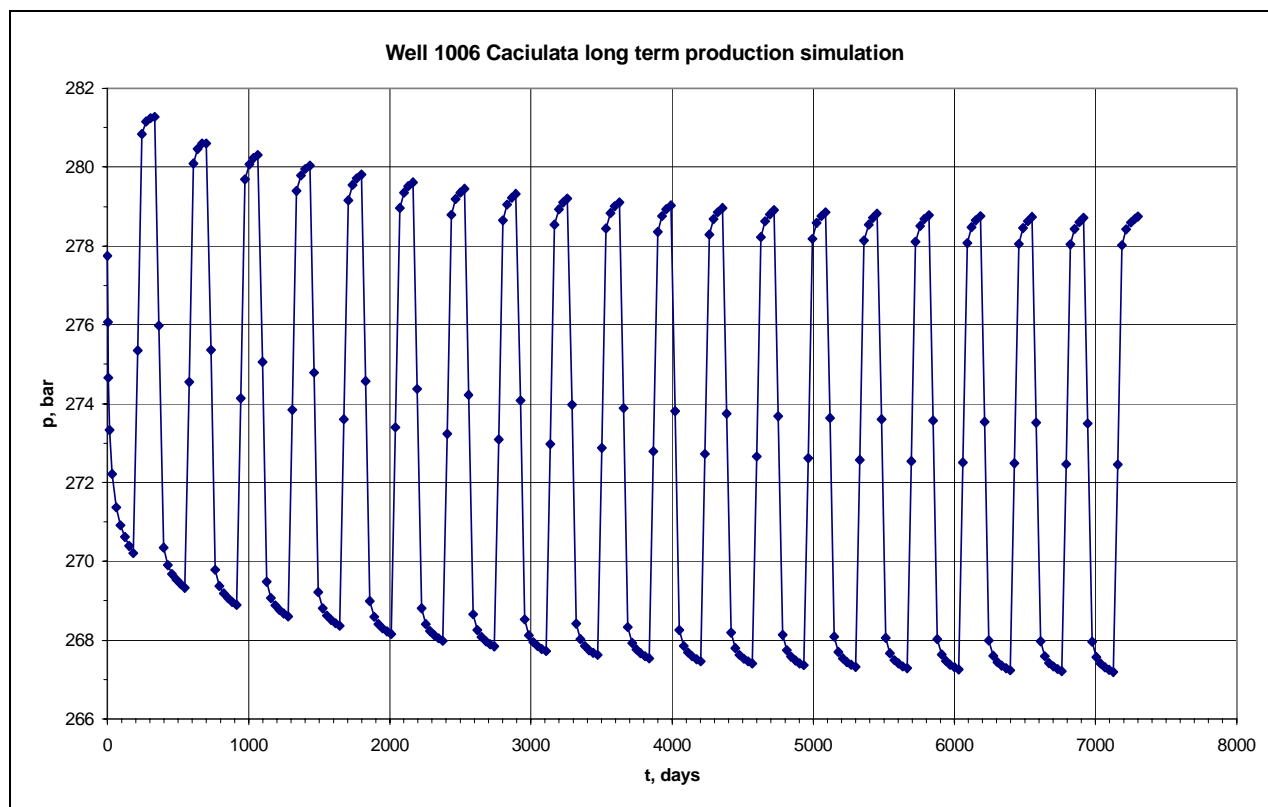


Figure 3: Long term production simulation (by Miklos Antics)

The well operates during winter at a maximum flow rate of 16 l/s geothermal water (57.6 m³/h), so the corresponding flow rate of the associated combustible gases will then be 126.72 m³/h. During summer, the well operates at a maximum flow rate of 6 l/s geothermal water (21.6 m³/h), so the corresponding flow rate of associated combustible gases will then be 47.52 m³/h. The annual average geothermal water flow rate is 9 l/s (32.4 m³/h), therefore the annual average flow rate of the associated combustible gases is 71.28 m³/h.

By using the associated combustible gases as fuel, the maximum heat flux available by burning it is close to 0.7 MW, therefore an economy of 791 tons can be achieved from these gases alone. Considering a reference outlet temperature of 30°C, the maximum heat flux available from the geothermal water nears 3 MW.

As a result, the investment expenses incurred for building the recovery plant for geothermal gas should be paid back in a short period of time. After processing, the collected data will set up the basis for selecting the type and optimising the design of the combustible gas recovery plant. The on-site analysis showed that, for a first glance, conditions are favourable for implementation on well 1006, owing to the nearby heat load and the availability of onsite housing facilities.

The main users supplied at present with geothermal heat consist of two hotels and a few villas located close to the production well. The geothermal water is used for both space heating and sanitary hot water supply. The heat depleted geothermal brine is used downstream for health and recreational bathing in outdoor and indoor swimming pools, as well as for balneology in the treatment facilities of both hotels suggesting cascading direct uses of geothermal heat.

The larger of the two hotels has a nominal heat demand nearing 700 kW, of which about 175 kW for sanitary hot water and 525 kW for space heating. Under the climatic conditions prevailing in the Caciulata area, the annual heat load is equivalent to about 2,900 degree-days. The annual heat consumption of this hotel is therefore 710 GJ (2,550 MWh), of which 180 GJ (640 MWh) mobilised by sanitary hot water and 530 GJ (1,910 MWh) by space heating.

The smaller hotel has a nominal heat demand nearing 500 kW, of which ca. 125 kW for sanitary hot water and 375 kW for space heating. The annual heat consumption of this hotel is therefore 505 GJ (1,820 MWh), of which 125 GJ (455 MWh) address sanitary hot water and 380 GJ (1,365 MWh) space heating.

The villas connected to the geothermal heating system have a total nominal heat demand of ca. 300 kW, of which 75 kW for sanitary hot water and 225 kW for space heating. The total annual heat consumption of these villas is therefore 305 GJ (1,100 MWh), of which 75 GJ (280 MWh) allocated to sanitary hot water and 230 GJ (1,100 MWh) to space heating.

The total nominal heat demand of the geothermal heating system stands at about 1.5 MW, of which 375 kW allocated to sanitary hot water and 1,125 kW to space heating. The total annual heat consumption of all users connected to the geothermal heating system amounts to ca. 1,520 GJ (5,470 MWh), of which 380 GJ (1,375 MWh) supply hot tap water and 1,140 GJ (4,095 MWh) the space heating demand.

The geothermal brine used for balneotherapy requires a temperature close to 37°C. When the outlet temperature of the heat depleted geothermal water is not high enough (during the hot season and at low heating loads), it is mixed with the source geothermal water. The annual average outflow temperature of the total amount of geothermal water used for the heating system averages therefore 40°C. Considering 10% heat losses in the system, the maximum geothermal water flow rate required by the heating system is close to 7 l/s, the nominal geothermal installed power standing at 1.9 MW (of which 0.2 MW address medical uses).

A comparison should be made between different types of fuels that can be used for household needs (cooking, heating, etc.), considering that there is no natural gas distribution network in the area. Many potential users welcome the idea of using a gas fuel fed by a pipe network an attractive issue indeed, as there no longer exist storage problems, nor residues, nor pollution with ash or pollutant gases whatsoever. In the area of Calimanesti-Caciulata spa, all potential users are eager to use combustible associated gases from geothermal water to meet their domestic needs. The potential users agree to support investment costs for the gas distribution network from the test well to the consumers, but if and only if the supply is ensured daily over at least 2-3 years. Accordingly, they intend to sign a firm contract with the well owners. At these conditions, the well owners agree to sign this contract with end users of combustible gases only after a probative period demonstrating the feasibility of the concept. To the author's knowledge, no contract was signed as yet.

Close to the test well is located another large hotel, with a capacity exceeding 200 rooms, which now uses geothermal water for heating, and requires a clean fuel such as combustible gas for cooking and laundry. Near the well is also located a restaurant and several private buildings which are candidate customers.

5. THE COMBUSTIBLE GEOTHERMAL GASES SEPARATION PLANT

A storage and degassing tank already existed on site, close to the well head, but the separated combustible gasses were wasted and lost (burned on at end of a pipe). In order to upgrade the existing degassing vessel performance, the specialists of ICPET Bucharest (the Thermal Energy Research and Design Institute - the technical co-ordinator of the INCO project) and of the GeoProduction Consultants (the scientific co-ordinator of the INCO project) performed a thorough redesign of the geothermal combustible gas processing line. In so doing, the governing rationale consisted of perfecting and complementing the hardware available on site, rather than implementing a new separation/processing system.

The exercise addressed the design of a degasser outfit, a droplet separator and a gas cooler (Figure 4), achieving gas drying and cooling performance compatible with end users' requirements.

- degasser dome: added to the top of the existing horizontal separator vessel, it aims at accommodating the two phase mixture by enhancing the separated gas escape and reducing (draining) water carry over. It elsewhere contributes to lowering gas outlet temperatures;

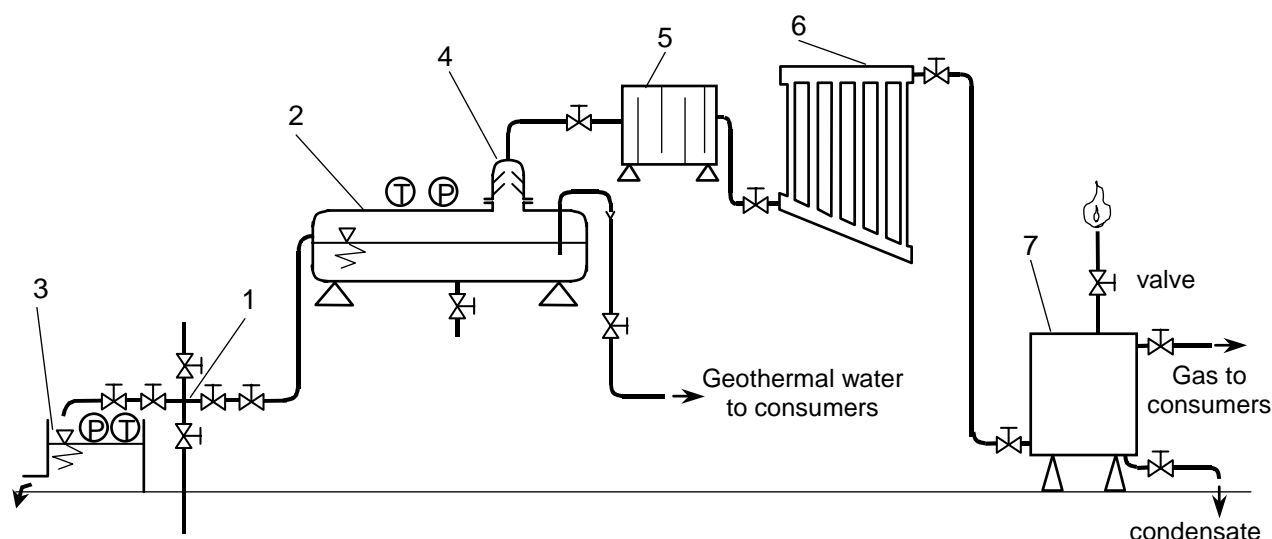


Figure 4: Layout of the plant fitted with equipment for associated combustible gas recovery
Legend: P – sampling point; T – temperature measurement point; 1 – well head; 2 – degasser; 3 – water flow measurement vessel; dome with chicanes; 5 – droplet separator; 6 – cooler; 7 – gas stocking vessel; 8 – hydraulic valve

- droplet separator: acts as demister, therefore diminishing significantly the geothermal gas moisture (carry over and condensate water). As a matter of fact, target design figures allow decreasing by one order of magnitude the former moisture content, which therefore drops from 40% to less than 5% wt a value adequate for downstream geothermal gas utilisation. A silica gel cartridge could be added as a supplementary drying facility to achieve a close to 1% moisture content;
- gas cooler: it achieves the ultimate, season wise, drying and cooling figures.

	summer	winter
outlet temperature, °C	32.5	25.5
moisture content, %wt	4	3

The aforementioned degassing, demisting, and cooling equipment was assembled on site in compliance with a compact, easily accessible to monitoring and maintenance staff, and environmentally safe design with liquid drain pipes, a H₂S filter, and backup air fan facilities added accordingly.

In the future, the following segments need to be finalised:

- evaluation of the existing and potential uses of geothermal heat and separated geothermal gas over the whole Caciulata, Cozia and Calimanesti area;
- impact assessment of replicate developments of the geothermal gas processing/recovery concept within the neighbouring Central/Eastern European countries enjoying similar, gas rich, geothermal fluid environments and end uses.

Last, but not least, future development prospects, on the investigated area, are appealing and innovative in scope. The geothermal separated gas potential can be readily estimated at about 1.4 million m³_N (CH₄ equivalent)/yr at present (self flowing discharge) ratings. Would the wells

be adequately stimulated by acidising and their production sustained by artificial lift, this figure could realistically rise up to 2.6 million m³_N/yr.

This energy source, independently from geothermal water heat exchange, could meet a variety of local demands: heating, tap hot water, domestic uses and, ultimately, power generation. The latter could be designed according to a cogeneration cycle, securing 1 MW_{el} and 1.3 MW_t installed power and heat capacities.

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