Utilization of low enthalpy geothermal energy in Bulgaria

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Abstract. Bulgaria is relatively rich in geothermal water of temperature in the range of 25°C-100°C and the total flow-rate exceeds 3,000 L/s. Generally, there are more than 170 geothermal fields: 102 of them are state-owned and the rest of them – belong to some municipalities. Up to 72% of the total known flow-rate from the reservoirs has a comparatively low temperature - up to 50°C. Flow-rates for individual sources vary within 1-20 L/s for most of the reservoirs. The highest temperature (approximately 100°C) is measured at the surface in Sapareva Banya near Rila Mountain. TDS (total dissolved solids) vary between 0.1 g/L and 1.0 g/L for most of the reservoirs in Southern Bulgaria, while in Northern Bulgaria it is significantly higher – the maximum is up to 150 g/L. The installed capacity amounts to about 97.5 MWt (for 2017), excluding the low grade energy use by ground source heat pumps (GSHP). Geothermal energy has only direct utilization - in balneology, heating of buildings, air-conditioning, greenhouses, geothermal ground source heat pumps, direct thermal water supply for industrial processes. Geothermal water is also used for bottling of potable water and soft drinks. Most of the hydrothermal sites are developed as mountainous or sea resorts. Electricity generation from geothermal water is not currently available in the country.

1. INTRODUCTION
Bulgaria is located in SE Europe and covers 23% of the Balkan Peninsula (Fig. 1). The territory of Bulgaria is approximately 111,000 square kilometers and it has a population of about 7,150,000 (2015). Its mineral (thermal) waters have been subject of exploration and exploitation from ancient times until present. Some Paleolithic and Neolithic settlements have been built around thermal springs. The ancient use of thermal waters had rapidly increased during the time of the Roman Empire (period 46-395 A.D.). More than 25 site remains of buildings and bathing facilities from that time were revealed.
The capital of Bulgaria, the city of Sofia, is one of the three capitals in Europe, along with Reykjavik (Iceland) and Budapest (Hungary), which was established around a thermal water source in ancient times – nowadays this natural spring still exists and it is called "Sofia-centre spring".
The natural thermal springs and thermal water discovered later by hundreds of boreholes in the country have only direct application because the groundwater temperature is below 100°C. Only eleven geothermal fields have temperature higher than 75°C and the total flow rate in each of them varies between 6 L/s and 33 L/s. (Fig. 2) [5].

![Location map](image1)

**Fig. 1.** Location map

![Geothermal fields map](image2)

**Fig. 2.** Geothermal fields with temperature higher than 75°C in Bulgaria
The types of application include mainly balneology (treatment, prevention, relaxation, sanitary needs and pools) and to a much lesser extent – energy use for space heating, greenhouses and in industrial processes. Up to 70% of the mineral waters are slightly mineralized (total dissolved solids, TDS, is less than 1.0 g/L) and are also suitable for bottling of potable water and soft drinks. Furthermore, thermal water from some deposits is used for central water supply where no alternative is available (particularly in some relatively new spa-hotels centres).

Ground source heat pumps (GSHP) are increasingly applied along with the traditional installations for hydrothermal energy use. GSHP systems are assembled in family houses, blocks of flats, offices and industrial buildings in different sites of the country. They provide heating, cooling and domestic hot water. Information on the exact number of units, their installed capacity and type (air to water, water to water) is not officially available, hence not discussed in this paper.

This article presents the current thermal water utilization as of 2017 and the main factors influencing the low enthalpy geothermal energy development in the country as well as the hydrogeological conditions, the physical and chemical properties of thermal waters and the potential for future development of this energy sector.

2. GEOLOGICAL AND HYDROGEOLOGICAL BACKGROUND

The territory of Bulgaria is built up by sediments, intrusive and metamorphic rocks of different origin with various lithologic and petrologic compositions, varying from Precambrian to Quaternary age [8] [3] [11]. The territory covers parts of two major tectonic units: the northern part of the Alpine thrust belt in the Balkans, and its foreland - the Moesian platform [9] [10]. The Alpine thrust belt is divided into two orogenic systems: the South Carpathian system, which is poorly exposed in the northwestern corner of Bulgaria, and the Balkan system, subdivided into three main zones (Balkan, Sredna Gora, and part of Moravia–Rhodope zone, named Rila–Rhodope massif). The Moesian platform (completely covering Northern Bulgaria) is located in both Bulgarian and Romanian territory. The platform has a Caledonian–Hercynian basement and a cover of Upper Paleozoic and Mesozoic sediments. Up to 1,000 m thick artesian aquifers (Upper Jurassic-Lower Cretaceous) are found in the plate built up of extensively fractured and highly permeable limestone and dolomite. It is the biggest geothermal reservoir in the country.

Metamorphic and magmatic complexes are mainly spread in the three folded tectonic units: Balkan zone, Sredna Gora zone and Rila–Rhodope Massif (Fig. 3). Geothermal waters are formed primarily in granites and gneiss.

The Balkan Zone is presented by Alpine structural complexes [8]. The Sredna Gora Zone is bounded by the Balkan mountain to the north and by the Maritsa fault to the south. Typical for the zone is the wide development of the Pre-Alpine structural complexes split by enormous Caledonian–Hercynian granitic batholiths. The Rila–Rhodope Massif consists of four structural complexes: Archaic, Proterozoic, Caledonian–Hercynian and Alpine. The foundation of the massif is formed by Pre-Cambrian complexes and by the Caledonian Structural Stage of granitic rocks in the West Rhodope Block. The second important stage in the formation of the massif occurred in the young-Alpine age, when depressions with thick volcanogenic–sedimentogenic deposits were formed.

The geological and hydrogeological conditions forming hydrothermal deposits in Bulgaria are summarized in numerous publications [6] [4] [7] [5] [1]. The territory of Bulgaria is characterized by complex hydrogeological conditions. The northern part of the country, as mentioned above, is a large artesian basin, consisting of widely distributed layered aquifers divided by water impermeable layers.
Groundwater temperature there reaches more than 100 °C at the bottom of some boreholes (Vidin, Slanotran, Pleven sites etc.). The high water salinity impedes direct application due to the risk of scaling. The aquifers are penetrated by hundreds of deep boreholes (some of them more than 6,000 m deep). Most of these boreholes have been drilled for the purpose of oil and gas prospecting and exploitation. More than 2,000 of the boreholes (research and production ones) have been decommissioned and cemented after their exploitation in order to avoid mixing of groundwater with very high TDS (up to 150 g/L) with fresh water from different upper aquifers. Only some geothermal fields and occurrences, along the Balkan and some other ones in the north-eastern part of the basin are currently exploitable for different applications – balneology, space heating, greenhouses, and central thermal water supply.

![Geothermal fields and sources in Bulgaria](image)

**Fig. 3.** Geothermal fields and sources in Bulgaria

The second type of hydrothermal deposits – fractured confined systems, is found mainly in the Southern part of the country. These deposits have a sporadic distribution and are attached to tectonic zones and regions characterized by higher heat flow values. Most often the water there rises upward along faults and forms natural springs at the surface. That is why more than 95% of all natural geothermal (mineral) springs occur in Southern Bulgaria. In some cases thermal water is discharged in more recent unconsolidated sediments (secondary reservoirs), which are deposited in graben depressions. More rarely, there are cases where karstified limestone and marble become secondary collectors for thermal water. Additional boreholes are drilled to increase the water quantity in many of these fields. The TDS of most geothermal natural springs and boreholes is lower than 1 g/L in Southern Bulgaria.

According to the Water Act, 102 of all hydrothermal fields in Bulgaria are specified as exclusive state property. The rest are municipal property. Up to about 70 state-owned fields have been identified as being granted leased to municipalities for a period of 20 years.
The Water Act defines three categories for thermal water utilization: water supply (when no alternative is available), treatment and rehabilitation in hospitals and specialized medical centres and the third category combines all other applications - balneology and energy.

3. UTILIZATION OF LOW ENTHALPY GEOTHERMAL ENERGY
The major factors that contribute to the geothermal development in Bulgaria are: long tradition, favourable climate, appropriate thermal water composition and a developed spa system. In spite of a relatively good hydrothermal capacity of 9,957 TJ/year (2,765,855 MWh or about 315 MWt) [5], the application of thermal waters is still limited. The exploitable part of the discovered quantity is currently about 25-30%, of which 4.3% of which is utilized under a concession regime (mainly for bottling of mineral water) and 26.6% is available to users for all other applications, through permits (Ministry of Environment and Water). The installed thermal capacity (2017) amounts to about 97.5 MWt, excluding GSHP.

Due to the relatively low temperatures (below 100°C), thermal waters have only a direct application. The variety of uses nowadays includes: balneotherapy (prevention, treatment and rehabilitation, bathing and swimming pools), space heating and air-conditioning, greenhouses, geothermal ground source heat pumps, direct thermal water supply, bottling of potable water and soft drinks.

3.1. Electricity generation in Bulgaria
According to National Statistic Institute, the total electricity produced in Bulgaria for 2017 amounts to 48,456,000 MWh (5532 MWt) (Fig. 4). Most of the electricity is generated by Thermal Power Stations (TPS) and by Nuclear Power Plant (NPP) in Bulgaria. The renewable energy sources (including hydroelectric power stations) produce about 9.1% of the national electricity.

![Electricity produced in Bulgaria during 2017](image)

**Fig. 4. Different electricity producers in Bulgaria**

Electricity generation from geothermal water is not currently available in the country but there are 11 sites where the water temperature is within the range 75-98 °C and some of them could be used for this purpose (binary cycle power plants) for local needs in the near future, if there is interest from investors.

3.2. Balneology
Balneology has always got a leading role (59.3%) in the use of thermal water in the country (Fig. 5). It is divided as follows: treatment, rehabilitation, prevention, relaxation, sanitary needs and pools.
One example of the traditional use of mineral water in this territory, for bathing, primitive medical treatment and relaxation, could be seen at the very centre of Sofia city: Roman bath (ancient - II century A.D.), Turkish (medieval - XVI A.D.) and Bulgarian one (the beginning of XX century) (Fig. 6). Recently, the last one was transformed into a Museum of Sofia.

3.3. Water supply
Direct supply with mineral water is mainly connected to balneology. It is typical for many spa resorts among mountain areas as Chiflika, Velingrad, Ognyanovo and many others as well in some see resorts along the northern Black Sea coast: Sv.Sv. Konstantin & Elena, Zlatni pyasatsi, Albena, Rusalka and others (Fig. 7). Drinking mineral water from taps is free of charge all over the country.
Fig. 7. Mineral water used in mountain and sea resorts

3.4. Bottling
This activity is regulated by the Law on Concessions. There are several major reasons for the development of bottling, including: generally low TDS (<1 g/L) of the thermal waters in Southern Bulgaria; a wide variety of chemical compositions that provides an opportunity for bottling of potable water as well as of mineral water for drinking in prescribed doses; and short-term payback period. Production meets mainly the demand of the local market. Bottling of mineral potable water (4.3%) is one of the very fast developing businesses during last 30 years. The number of bottling factories (Fig. 8) increased from 3 to more than 40 in 3 decades only. The use of bottled mineral water was not common almost to the end of last century but consumption of such water increases rapidly in the last 30 years in Bulgaria.

Fig. 8. One of the factories for bottling of mineral potable water

3.5. Greenhouses
The greenhouses produce mainly vegetables and flowers for the local market. The share of water used for greenhouses is insignificant. It accounts only about 1.8% of the total thermal water use. No progress has been observed in applications like space heating and greenhouses. The greenhouses are high energy consuming systems and their operation under existing climatic conditions and available market is not cost effectively at present. Thermal water potential in the country is suitable mostly for low temperature floor heating or for systems assisted by convectors. Such installations need high primary investments and at this stage of economic development they are not competitive to the air-conditioning systems widely available on the market. The geothermal water application in some relatively large greenhouses (the villages of Levunovo, Kazichene etc.) was abandoned because of cheaper and easier to maintain systems. Generally, the use of geothermal water for heating greenhouses decreases in recent years.

3.6. Space heating
Heating is provided only to individual buildings (1.3% of the total geothermal water used) and it is not connected in a district heating system. Heating installations are assisted by plate heat exchangers (Sapareva banya, Varna etc.). In addition, they heat domestic water and are in operation for about 200 days/year.
3.7. Other applications
Up to 6.6% is still used for some other purposes – mainly for laundering, dish washing as well bathing in local public baths etc.

CONCLUSIONS
The main conclusions for utilization of low enthalpy energy in Bulgaria could be summarised as follow:

- Recently, heating of buildings and greenhouse development have been declining, while balneology (spa-centres) has been showing progress over the last thirty years. Thermal water is being currently used for space heating and domestic hot water in only a few balneological sites. Many old heating installations in poor technical condition have been abandoned and only a small number of new installations have been constructed.
- The low-enthalpy hydrothermal resources in the country have the potential for future development as direct application. The existing know-how in geothermal energy use for space heating and air-conditioning, combined with the new administrative regulations, will provide better conditions for the utilization of these renewable sources.
- The major factors promoting geothermal development in Bulgaria are the long existing tradition in thermal water use, favourable climate, appropriate thermal water composition for therapy as well as for bottling of potable water and soft drinks and a well developed spa system. A progress in balneological application in last 30 years has been achieved due to the significant growth of hotel construction in the mountain and seaside resorts. In most of them water is used for relaxation and small pools.
- Electricity generation from geothermal water is not currently available in the country but some binary cycle power plants could be built, if any investor be interested. Obviously, such systems will be only of local importance because of very limited geothermal potential for this kind of activity.

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