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Heat from Very Low Enthalpy Geothermal Source versus Solid Fuels in the Felix-Sanmartin Area, Romania

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ABSTRACT:

Sanmartin is a village located close to Felix Spa, on the way to Oradea, and in the last 10-15 years developed as a new residential area for the people previously living in the city. The source of the heat is more than 90% solid fuel (lumber and coal). Geothermal water with temperatures between 35°C and 55°C is available at rather shallow depth, between 50 and 150 m, with a chemical composition that causes no problems for direct uses. This paper presents a comparison between systems using geothermal energy and systems that produce thermal energy from solid fuel. The systems are evaluated technically, economically, and in terms of environmental impact.

1. INTRODUCTION

Sanmartin is a small village located 7 km east of the City of Oradea, close to Felix Spa. Due to its location, in the vicinity of a large and well-known spa and close to a large town, it has become very popular for building new houses (permanent residences and vacation homes).

The heat produced today in the residential neighborhood of Sânmartin is mostly produced by burning fuel wood. Each residential house is equipped with its own heating station with gasification having as fuel source wood. A small part of the heat consumers in the residential neighborhood have as energy source other than solid fuels, such as: natural gas, electricity, geothermal energy exploited trough direct systems or by interposing a heat pump, solar power systems.

The neighborhood was built in the past 10 years, having approximately 200 houses, and is growing rapidly.

Even if wood is renewable, and current tendencies are to encourage the use of renewable fuel, the presence of the geothermal reservoir Felix – 1 Mai in this area, justify an analysis of the impact of changing the heat production from solid fuel to geothermal.

The geothermal reservoir is characterized by relatively low temperatures, but carefully monitored and controlled exploitation allows obtaining considerable quantities of heat without harming existing consumers of geothermal fluid (tourist centers of Felix Spa).

For obtaining useful heat from a geothermal source with a very low enthalpy for a residential house or neighborhood there are some recommendations:

- Cascaded use of heat
- Splitting the total energy depending on temperature of geothermal fluid
- For temperatures between 40-50°C trough large areas of heat exchange, production of domestic hot water
- For temperatures between 35-45°C space heating (systems with floor heating, systems with radiant panels, systems with forced convection)
- For temperatures between 25-35°C heating of various technical spaces (car garage, deposits, food storage and other)
- For temperatures between 20-30°C heating of water from swimming pools
- For temperature between 15-25°C laundry drying, drying of pedestrian surfaces, drying of car accesses
- For temperature between 5-15°C for snow and ice melting from the above mentioned surfaces.
- If the needed geothermal fluid for space heating is only available with temperature less than 35°C then it is imposed to introduce heat pumps in the heating system.

For consumers where the heating systems are sized in order to use solid fuel it is necessary to rebuild the heating system and a possible adaptation to enable it to obtain the necessary flow of heat from geothermal source. The geothermal systems implementation requires some measures for fuel wood consumers, such as:

- Supplementary thermal insulation of the residential house where is need so the necessary flow of heat per house is lowered
- Increase of heat exchanging surfaces so that it can be obtained the same flow of heat needed for the residential house using heating agent characterized by temperatures lower than the temperatures of systems using solid fuel
- Replacement of classic radiators with systems that use forced convection heating
- Introducing heat pumps in the heating system
- For the preparation of domestic hot water from geothermal sources is necessary to increase the amount of water accumulation in order to ensure the hot water consumption

In case of the constructions to be completed, even since the design stage of the heating installation will take account of the geothermal potential that characterizes its vicinities. To implement systems using geothermal heating there are used large surfaces for heat exchange (floor heating systems or radiating panels) recommended by the low temperatures which characterize the geothermal fluid from the Felix – 1 Mai deposits.

2. THE GEOTHERMAL RESERVOIR

The geothermal reservoir in the Sanmartin area has particular geo-structural conditions. Due to the interconnection of multiple tectonic elements on the contact between the Carpathian Mountains and the Pannonian Basin, as well as to the subsidence of the Borod and Beius intermountain basins, a large number of faults are encountered over less than 20 km^2.

The geothermal aquifer in the Sanmartin area is located in heavily fractured limestone between 80 and 175 m deep, and is usually referred to under the name Felix Spa. Although it is separated in space from the Oradea reservoir, both horizontally and vertically, the two geothermal reservoirs are hydro-dynamically connected, being a unified hydro-geothermal system, actually the final part of the Mesozoic regional hydro-structure Padurea Craiului. The natural springs and the wells in the area have a similar hydrodynamic behavior, with rapid interference effects.

The natural recharge rate was calculated at about 300 l/s based on the only interference test carried out in 1979 (Paál, 1979). The hydro-geological (Cohut & Paál, 1985), hydrochemical (Ţenu, 1981), and geothermal (Veliciu, 1986) research proved that the reservoir is recharged via a deep pathway along an important structural line (the Velenta fault, oriented NE-SW), excluding the lateral recharge.

The convective system in the Oradea area is recharged from the East, mainly through the system of faults and fractures delineating the Borod basin, but also through strata surfaces. Cold waters infiltrated in the karstic areas of the Padurea Craiului Mountains are flowing westward and downward, reaching higher temperature layers, and are starting the thermal convection process in the entire Triassic carbonate stack, 500 to 800 m thick.

The variation of the average geothermal gradient in the Oradea area from 2.5°C per 100 meters in the east, to 4.5°C per 100 meters in the west, over only 10 km, while the geothermal heat flux density is constant, can only be the consequence of the convection caused by the inflow of colder water from the east, along a major fracture network know as the Velenta fault, along which the main part of the water is channeled to the Felix Spa area.

2.1 Physical and Chemical Properties of the Water from the Felix Spa Reservoir

In reservoir conditions, the fluid from the Felix geothermal reservoir is a complex sub-saturated solution of dissolved solids and gasses. The content of total dissolved solids (TDS) is 0.9-1.3 g/l, the main ions being Ca, Mg, Na, K, Li, Sr, Mn, and Fe. The phenolic compounds and organic substances are below the lower limits acceptable for surface waters, therefore no further toxicity tests have been carried out. There are low concentrations of non-condensable gasses (NCG), mainly CH_4 and traces of CO_2.

The geothermal water contains, in concentrations above those admissible for potable water, Radium 226 and Radon 222, which is a natural radioactive gas resulting from the disintegration of Radium. The concentrations are between 0.5 and 3.5 pCi/l for ^{226}Ra and between 0.5 and 3.2 pCi/l for ^{222}Rn, which makes the geothermal water undrinkable, but also strongly contributes to its therapeutic effect in health bathing.

The physical properties of the geothermal fluid have been determined for the reservoir conditions in 1980 exclusively based on their variation with the temperature and mineralization, the values being:

- saturation pressure: 0.2 MPa;
- density: 992 kg/m^3;
- dynamic viscosity: $0.65 \cdot 10^{-3}$ Pa·s;
- compressibility coefficient: $4.55 \cdot 10^{-4}$ MPa^{-1};
- volume factor: 1,033;
- specific heat: 4,162 kJ/kg:
- thermal conductivity: 0.683 W/m/K.

Calculations based on the chemical composition of the geothermal fluid (and confirmed by practice) show a very low scaling potential, and only at temperatures below 20ºC (Rosca, 1993). The geothermal water from the Felix Spa reservoirs is neutral (pH 6 at 20ºC). Corrosion problems caused by the geothermal fluid have not been reported. As the reservoirs are located in fractured limestones, no sand was reported to exist in the geothermal water.

2.2 The Available Geothermal Energy

The exploitable flow rate (without reinjection) from the Oradea and Felix Spa reservoirs was set by the National Agency for Mineral Resources to 300 l/s annual average (the natural recharge flow rate), in order to prevent reservoir pressure decline during long term exploitation.

Felix Spa is probably the best known of the Romanian spas, and definitely the largest. It has a total of more than 7,000 beds, 5,750 of which are in 12 hotels ranging from 1 to 3 stars, and 1,250 beds in villas of different comfort levels. Each hotel has its own treatment facilities. A physical recovery hospital with 150 beds is also operated in Felix Spa.

Therefore, the geothermal water supply for Felix Spa was considered a priority. The total exploitable flow rate in Felix Spa was set by the National Agency for Mineral Resources to 210 l/s annual average, in order to prevent the reservoir pressure decline and to protect the natural reservation of *Nymphaea Lotus*, variety *Thermalis*, a Tertiary remnant which grows naturally in geothermal ponds, a quite uncommon occurrence at this latitude (about 45ºN) and therefore a tourist attraction.

The remaining 90 l/s annual average flow rate can be produced from the Oradea reservoir. A higher exploitation will only be approved by the National Agency for Mineral Resources if at least the additional extracted flow rate will be reinjected.

Out of the 9 geothermal wells drilled in Felix Spa, only 6 are currently in use. The two oldest wells in Romania were drilled in Felix Spa, the first in 1885 (which can still produce up to almost 200 l/s), and the second in 1887 (now closed). All wells are producing by artesian discharge.

The geothermal water demand in Felix Spa can only be estimated, as the real consumption is not metered and therefore there are no data available. The geothermal water is only used for health bathing, and the consumption was estimated at 100 – 110 l/s, with the peak load during the summer, when it is used in all outdoor swimming pools for recreational bathing as well.

It can thus be estimated that, from the total flow rate approved by the National Agency for Mineral Resources, about 100 l/s is available for energy uses in the Sanmartin village.

Temperature and flow rate measurements have been carried out for all wells and natural springs in the area of the Felix Spa reservoir. The average wellhead temperature of the geothermal water from the wells closer to the Sanmartin village is 42°C. Considering a 20°C reference temperature for the heat depleted geothermal water, the heat flux available for energy uses in Sanmartin is:

$$\dot{Q}_g = \dot{m} \cdot c_w \cdot \Delta T = 0.1 \cdot 4.165 \cdot 22$$

$$\dot{Q}_g = 9.16MW \quad (1)$$

3. RESIDENTIAL AREA SÂNMARTIN

The new residential area of the city of Sânmartin is defined by a number of 200 residences. These houses were built in the past 10 years, fact that allowed the use of latest construction materials. The constructions structure is made from materials that have very low thermal conductivity and a percentage of 90% from these houses have a supplementary thermal insulation. The high degree of insulation allows the use of the global heat losses coefficient "k" in the calculus of the needed heat, having a value close to 1 W/m^2K.

Medium surface of a dwelling is about 200 m^2 and the total surface S_T can be approximated with the equation:

$$S_T = n \cdot S_M \quad (3);$$

Where S_T – the total surface

n – number of dwellings

S_M – medium surface of a dwelling

Using the above equation it can be determined the total surface that has to be heated.

$$S_T = 200 \cdot 200 = 40000m^2 \quad (4)$$

After an analysis on Romania, from a meteorological point of view, it was divided into three climatic zones and it has been established for each zone the minimum temperature. For the city of Sânmartin the established zone is the I zone and it is characterized by a minimum temperature of -12°C.

The 5th equation is often used in practice when it is needed to estimate the thermal load of housing and it allows us to make an estimation of the needed heat for each house.

$$\dot{Q}_{Sh} = k \cdot V \cdot \Delta T \quad (5)$$

Where $\dot{Q}_{Sh}[W]$ - the rooms needed heat;

$V[m^3]$ - volume of air to be heated;

$\Delta T = T_i - T_o[°C]$ - temperature difference between inside and outside;

$T_i[°C]$ - inside temperature;

$T_o[°C]$ - outside temperature.

The standard height of a residential house is of h=3m.

Using the fifth equation we can determine the needed heat for a residence.

$$\dot{Q}_{Sh} = 1 \cdot (3 \cdot 200) \cdot [20 - (-12)]$$

$$\dot{Q}_{Sh} = 19.2kW \quad (6)$$

The needed heat to heat the entire residential area can be determined with the seventh equation using the fifth.

$$\dot{Q}_{Sht} = k \cdot (h \cdot S_T) \cdot \Delta T \quad (7)$$

$$\dot{Q}_{Sht} = 1 \cdot (3 \cdot 400) \cdot [20 - (-12)] = 3840kW \quad (8)$$

Based on data provided by the city hall of Sânmartin we can estimate an average number of three people who live throughout the year in a residential house. It is considered a average consumption of domestic hot water by a person of $1.4 \cdot 10^{-3} kg/s$. The ninth equation allows us to calculate the needed heat to prepare the domestic hot water for a residential house.

$$\dot{Q}_{hw} = n \cdot \dot{m} \cdot c_w \cdot (T_{bw} - T_{cw}) \quad (9)$$

Where $\dot{Q}_{hw}$ - heat flow required for domestic hot water preparation

n – number of persons

$\dot{m}[kg/s]$ - the average consumption of domestic hot water

$c_w[kJ/kg \cdot °C]$ - water's mass specific heat capacity $c_w = 4{,}17[kJ/kg \cdot °C]$

$T_{bw}[°C]$ - standard temperature of hot water (50°C)

$T_{cw}[°C]$ - conventional temperature of cold water (10°C)

$$\dot{Q}_{hw} = 3 \cdot 1.4 \cdot 10^{-3} \cdot 4.17 \cdot 10^3 \cdot (50 - 10)$$

$$\dot{Q}_{hw} = 0.7kW \quad (10)$$

The heat flow necessary to prepare the domestic hot water for the entire neighborhood is determined by the equation 11:

$$\dot{Q}_{hwt} = 3 \cdot 200 \cdot 1.4 \cdot 10^{-3} \cdot 4.17 \cdot 10^3 \cdot (50 - 10)$$

$$\dot{Q}_{hwt} = 140kW \quad (11)$$

The heat flow necessary for heating and preparation of domestic hot water for a residential house is obtained by:

$$\dot{Q}_h = \dot{Q}_{sh} + \dot{Q}_{hw} \quad (12)$$

$$\dot{Q}_h = 19.2 + 0.7 = 19.9kW \quad (13)$$

Equation 14 allows the calculus of the heat flow for heating and preparation of domestic hot water for the entire residential neighborhood:

$$\dot{Q}_{ht} = \dot{Q}_{Sht} + \dot{Q}_{hwt} \quad (14)$$

$$\dot{Q}_{ht} = 3840 + 140 = 3980kW \quad (15)$$

Following estimates and bibliographic data without any modulation of the deposits from Felix – 1 Mai perimeter, is found that the deposits are able to provide the heat needed for the residential neighborhood. The needed heat is satisfied using only a third part of the available geothermal water flow. The heat extracted from the geothermal water allows heating of buildings during cold season and domestic hot water preparation throughout the entire year.

4. GEOTHERMAL SOURCE VERSUS SOLID FUEL

4.1. Thermic aspects

4.1.1. Systems with solid fuel

Most consumers in this neighborhood have houses equipped with heating stations using wood as fuel. A very small part use, for heating source, boilers with lighters, pellets or coal.

The smoke flue:

In the case of systems that use heating equipments with solid fuel even since the construction faze of the house the notion of smoke flue appears. The smoke flue's complexity is given by the following factors:

- The resistance structure to sustain the smoke flue;
- The height of the smoke flue that is directly influenced by the buildings height and the impact on the environment;
- Relatively big diameters to allow the evacuation of burnt gases for the systems using forced burning as for systems using free burning
- Cleaning elements of the smoke flue that allowing it to be very air-proof;
- Elements that repel the weather phenomena (rain, wind, snow, thunders etc.)
- An important factor in the smoke flue construction is the thermic insulation degree which has the main role of maintaining the condensation point in favorable areas
- Equipments that collect and evacuate condensate
- Insulating equipment to prevent fire

Heating station room

Central heaters with solid fuel need spaces specially equipped to allow safe and optimum operation. The room needs to comply with the minimum required surface according to the solid fuel that it uses and its power. The room needs to be built from special elements (walls, ceiling, doors, windows, etc. that are fire resistant) and with a high resistance level structure. Conditions are imposed on airflow and the burnt gases evacuation from the room. It is needed a system that allows taking the minimum amount of oxygen needed for oxidation reactions. The heating station room has to be ready so that wood can be loaded into the boiler.

Wood storage

The wood storage is defined as a covered and well ventilated space. Ventilation is often realized naturally but there are cases when forced ventilation is necessary. Physical positioning of the wood storage is required to have access to it or next to it for large tonnage vehicles, which ensure the transportation of wood. On the other hand the storage must be placed so that allows an easy and fast alimentation of the boiler with fuel wood. From a constructive point of view the biggest restriction are the rules of prevention and firefighting. According to the type of fuel and more specifically its density and caloric power determine the dimensions of the wood storage. For increased efficiency is essential that the wood used in the burning process to have a humidity value around 15%. The wood used is mostly hardwood (beech, oak, maple, birch) which specific average caloric power for a humidity of 20% can be calculated with the equation 16.

$$H_S = 34611 \cdot c + 115170 \cdot h - 1510 \cdot n - 10733 \cdot o - 2100 \cdot a \quad (16)$$

Where: H_s – superior caloric power

c – participative mass of carbon

h – participative mass of hydrogen

n – participative mass of nitrogen

o – participative mass of oxygen

a – participative mass of cinder

We consider an average gravimetric composition of the essence of hardwood as being:

c= 0.393 kg C/kg fuel

h= 0.047 kg H_2/ kg fuel

o= 0.341 kg O_2/ kg fuel

n= 0.004 kg N/ kg fuel

a= 0.015 kg cinder/ kg fuel

w= 0.2 kg H_2O/ kg fuel

where: a – cinder; w – water.

Based on the equation 16 the medium superior caloric power of the hardwood is:

$$H_S = 34611 \cdot 0.393 + 115170 \cdot 0.047 - 1510 \cdot 0.004 - 10733 \cdot 0{,}341 - 2100 \cdot 0.015$$

$$H_S = 15317.6 kJ/kg \quad (17)$$

The medium inferior caloric power is:

$$H_i = H_S - 2420W = 14833.4kJ/kg$$

At a humidity of 20% the medium density of the hardwood is $\rho_l = 650kg/m^3$ and in this case the caloric inferior power H_{IV} of a cubic meter of hardwood is given by equation 18:

$$H_{IV} = 650 \cdot 14833.4 = 9641710kJ/m^3$$

$$H_{IV} = 9.6GJ/m^3 \quad (18)$$

In the wood storage the wood is deposited piled and stacked and a cubic meter of wood occupies a volume of 1.2 metric cubes in the storage. The occupied volume of the piled and stacked wood is named stere meter (1 m^3=1.2 m_{stere}).

In the climatic zone I where city of Sânmartin is situated, the annual average number of days in which is necessary to heat is 200 days and the domestic hot water is prepared throughout the entire year. Under these conditions the annual needed heat can be determined by the equation 19 for surfaces heating, 20 for domestic hot water, 21 for total heat needed.

$$E_S = \dot{Q}_{Sh} \cdot \tau_S \quad (19)$$

$$E_w = \dot{Q}_{hw} \cdot \tau_w \quad (20)$$

$$E_{ht} = E_S + E_{hw} \quad (21)$$

Where: $E_S[J]$ - annual heat for heating a house

$\tau_S[s]$ - time needed to heat a house

$\tau_w[s]$ - time needed to prepare domestic hot water

E_{ht} - total heat for a residential house

$$E_S = 19{,}2 \cdot 10^3 \cdot 200 \cdot 24 \cdot 60 \cdot 60 = 331{,}8GJ$$

$$E_w = 0{,}7 \cdot 10^3 \cdot 365 \cdot 24 \cdot 60 \cdot 60 = 12{,}1GJ$$

$$E_{ht} = 331{,}8 + 12{,}1 = 343{,}9GJ$$

The needed solid fuel volume V_{SF} for a year of heat production is calculated with the equation 22:

$$V_{IF} = \frac{E_{ht}}{H_{IV}} = \frac{343.9}{9.6} = 35.82m^3 \quad (22)$$

The needed solid fuel volume allows us to calculate the volume of the wood storage. For a residential house according to the conditions presented above and considering the efficiency of the heating station $\eta_{hs} = 0.85$ need a deposit of

$$V_{IFster} = V_{IF} \cdot 1.2 \cdot 1.15 = 49.43 \text{ ster meters.}$$

The optimum height which is recommended for the wood to be stacked is $h_{SF} = 1{,}8$ height that allows establishing the area occupied by solid fuel needed for one year.

$$S_{SF} = \frac{V_{IFster}}{h_{SF}} = 27.46m^2 \quad (23)$$

The time needed for wood to dry to humidity under 20% is recommended to be a calendar year. For this reason the area of the wood storage has to be twice the area occupied by the needed wood over one year:

$$S_{HSF} = 55m^2$$

Heating station

The main equipment for a system that runs on solid fuel is the heating station. These are mounted in specially equipped rooms that allow connection to a smoke flue. All the houses from the residential neighborhood of Sânmartin are equipped with modern boilers, boilers with solid fuel gasification. In most cases the boilers nominal capacity is between 25 kW and 35 kW. Heating stations are complex systems that have the following main equipments:

- Blower to ensure the required air for the oxidation process
- Boiler furnace made of high quality steel
- Water-air based heat exchanger
- Door for fuel supply
- Door for ash disposal
- Exhaust system for burnt gases
- Door for air intake
- Ash collector
- Condensate collector
- System regulating the flow of combustion gases
- Cooling circuit to prevent water overheating in the boiler
- Command and central system
- Equipment for measurement and control (thermometers, manometers, thermostat, power regulator)

Boiler operation

The wood's gasification process (pyrolysis) takes place in the upper side of the boiler trough the embers layer. Gas formed by burning wood is led to the burner nozzle and mixed with the secondary air where the process of oxidation takes place. The heat obtained at this level is transferred to water from the boiler and then led to spaces needed to heat and preparation of domestic hot water.

Boiler startup is realized by successively following the next steps.

In order to start the oxidation process of the solid fuel the first step is to get the nominal value of ignition temperature that characterizes the used fuel wood. Ignition temperature is obtained using highly flammable material and the boiler's loading is made gradually respecting the steps recommended by manufacturer. Maintenance of the burning process needs trained personnel because depending on the necessary flow of heat is recommended different fuel loadings in the boiler. For example during the hot season when the boiler is used only for domestic hot water preparation is necessary to supply fuel to the boiler furnace of maximum 50% and in times when there is no need for domestic hot water the oxidation process must be stopped completely so the condensation phenomenon doesn't appear. The condensation with tar is deposited on the surfaces of heat exchange significantly reducing boiler's efficiency. Boiler cleaning is done by every supply and every 3-5 days to discharge the accumulated ashes and is done a complete cleaning of the heat exchanging surfaces and the air supply nozzles. Due to high temperature at which the boiler is operating at a maximum of 14 days is mandatory to check and add water to the heating installation if necessary. Periodically the door hinges need to be adjusted and when it is necessary the door sealing cords of the doors for fuel supply and ash disposal need to be changed. The body of the air supply nozzle will be replaced periodically and once with it the gaskets.

The gas exhaust flue is recommended to be cleaned twice a year. Due to an inappropriate cleaning of the smoke flue, reducing its section, leads to a poor quality burning process because of the impossibility to exhaust the combustion gases.

Protection against boiler corrosion requires additional equipment that has the role to maintain a difference between the intake and outtake between 15°C and 25°C.

Excessive loading of the boiler when not working at nominal power, power interruptions, damage to recirculation pumps, damage to air intake systems, damage to the exhaust of the burnt gases system, human error in operation, etc. all these impose a protection system of the boiler against overheating. Most often it is used an accumulation tank (puffer), which allows a discharge of heat flow from the heating station so the heating station's temperature does not exceed the saturation temperature of water in the secondary circuit.

Maintenance staff of the heating station should be well trained both in terms of technical aspects of the station and rules of fire prevention and firefighting respectively labour protection rules.

Possibility of automation of heating systems with solid fuel is very limited and can be performed only on reduced time periods.

<u>4.1.2 Geothermal systems</u>

<u>Geothermal bore hole for production</u>

Even if the geothermal fluid has low and very low enthalpy the major advantage is the low depths to which it can be met, quartered in strongly fractured limestone formations. Depths in which the geothermal deposits are quartered in Felix- 1 Mai are between 80 m and 175 m. The drilling for geothermal bore holes at these depths can be achieved with equipment of small capacity, the same equipment that allows drilling for groundwater. Drilling costs are also heavily influenced by low depths through the simplicity of the used equipment for drilling as well as multiple costs in euros for a drilled meter. The drilling time at this depth is very short and the area occupied by the bore hole afterwards does not exceed in any case 1 m^2.

The deposits exploitation can be done by drilling more bore holes, the number of bore holes is given by the heat flow obtained from one geothermal bore hole depending on its flow of production and the operating temperatures.

<u>Heat flow exploitation systems from geothermal water</u>

The geothermal reservoir does not allow artesian operation reason for the installation must be equipped with a submersible pump. Both geothermal water chemistry and the relatively low temperatures allow the use of usual submersible pumps without experiencing difficulties in purchasing any of these equipments in terms of cost price and their constructive materials.

The geothermal fluid is led to the interior heating installation through pipes of polyethylene this being allowed by its low temperature. It must be given a greater attention to the thermal pipe trough which the fluid is introduced in the interior installation. Thermal pipe must be well insulated both in terms of hydrodynamic and thermal issues.

Mineral compounds which characterize geothermal deposits don't allow direct use of geothermal water. The geothermal system is fitted in binding with a heat exchanger. For a residential house with a needed heating energy up to 20 kW, heat exchangers are characterized by surfaces for heat exchange that have up to 3 m^2 with a maximum permissible flow not higher than 1 l/s. Heat exchangers are recommended to be heat exchangers with plates.

<u>Secondary circuit</u>

Particularity of secondary circuits is the need of large radiant surfaces of the use of systems with forced heat convection. Secondary systems are required to be: floor heating or use systems with forced convection. Where implementation is not possible for the two systems mentioned above it is recommended to use a water to water heat valve.

CONCLUSIONS

The available flow of geothermal fluid at the Felix- 1 Mai deposits is sufficient to ensure the flow of heat to the entire residential neighborhood Sânmartin.

Geothermal fluid chemistry that characterizes the Felix – 1 Mai deposits imposes special conditions of exploitation of deposits.

Physical surfaces for geothermal systems are characterized by surfaces between 0.5 and 8 m^2 and for systems using solid fuel the occupied surfaces can not be less than 65 m^2.

Geothermal system automation can be realized in percentage of 100% but in the case of systems using solid fuel it is required a daily presence of the human factor.

Environmental impacts in a fair exploitation of geothermal deposits is very low, close to 0 and for systems using solid fuel produce considerable quantities of carbon dioxide, ash, residual heat from the combustion gases discharged into the atmosphere. Reliability of geothermal systems is clearly superior to systems using solid fuel due to the number of elements that characterize each of the two systems.

From an economic point of view the price for a gigajoule obtained in the case of the two systems shows absolute advantages for using geothermal systems.

4.2 Comparative analysis between geothermal systems and solid fuel based systems

Geothermal Systems	Systems with solid fuel
Physical space needed	Physical space needed
In cases when the production and the reinjection bore holes are made for more residences, these being placed on a public space, the needed surface is given by the volume of the two heat exchangers used for heating and respectively preparation of domestic hot water. The surface occupied by the two heat exchangers can be up to 0,5 m^2. The required space is only restricted by the need of an interceptor in the floor so the water can be discharged in case damage to the system occurs. Where the production and reinjection bore holes are placed individually they occupy more space in the exterior, about 1 m^2 for the production bore holes and 1 m^2 the reinjection bore holes. The required space is the outdoors of the house and is composed of two rooms with lids. In cases when the system needs to be implemented with a heat pump the space needed for the equipment can reach 6 m^2.	For a residential house, like the one described in this paper, the needed space consists in indoor spaces for the heating station and the required equipments and outdoor covered and ventilated spaces required for the wood storage. The room surface for the heating station equipped with a puffer, recommended by the manufacturer, needs to be minimum 15 m^2. The station's room is equipped with a smoke flue and metal door and the room must be fireproof treated to comply with rules imposed against fires. The needed space for the calculated solid fuel, in the heating station subchapter, must be around 50 m^2. Also these spaces need to be equipped with firefighting equipments. The wood storage is mandatory to be built so it allows a natural air flow so the wood can dry to a level of humidity under 20%.
Technical aspects regarding geothermal systems	Technical aspects regarding systems with solid fuel
Station Assembly Transportation and installation of the station is relatively easy and in a short time because the necessary equipments are few and with a simple construction. Station operation Time needed for the system to enter nominal operation is short, a few minutes. Automation of the system is simple and can be achieved in a percentage of one hundred percent so that the human factor has to intervene only for periodic reviews or repairs. Maintenance works for geothermal systems The installation needs annually maintenance works, and when the heat exchanger's efficiency decreases it should pass trough chemical or mechanical cleaning.	Station Assembly Because of the volume and mass that characterize systems with solid fuel, transportation and installation of these require special equipment. Complexity of installation requires a mounting team that is made up of more members that are specialist in this field. Station operation Time needed for the system to enter nominal operation is fragmented trough several stages: boiler cleaning, getting the temperature of oxidation in order to produce the process of oxidation, load the solid fuel into the boiler, carrying out the process of oxidation throughout the entire mass. The needed time is tens of minutes. Automation of the system is complex, formed by a series of interrelated partial automations. During the operation it is necessary the participation of a qualified person at intervals not exceeding 12 hours. Automation of the system can be achieved only partially. Maintenance works for systems with solid fuel The supply with solid fuel is made annually and needs sizing work (length, thickness) that is imposed by the type of heating station with wood chosen. Stacking the wood, in the wood storage, to be dried to moisture levels below 20%. The fuel supply to the boilers is done manually at intervals not exceeding 12 hours. Boiler cleaning (condensate, ash, tar) is done at intervals of 3-5 days. At intervals of 14 days the water in the boiler is checked and refilled. After repeated heating it is necessary to adjust the boiler's door to ensure that it is air-proof.

	Annually the change of the sealing cords of the intake and evacuation doors is needed. Annually the smoke flue must be cleaned.
The environmental impact of geothermal systems	The environmental impact of systems with solid fuel
Geothermal waters from Felix – 1 Mai deposits will not constitute a source of pollution because the mineralogy load is low, does not contain any organic substances and dissolved gases that don't present tendencies to fill with slough nor are corrosive. Air quality is not affected by any parameters that characterize geothermal waters. The soil and water are affected only during the execution of the exploitation and reinjection bore holes but the surfaces intended for these works are very small and the effects on soil and water are little. Heat exploitation from the geothermal deposits is recommended to be a doublet (production and reinjection bore holes) but even if some areas don't allow it due to low temperatures is possible its discharge into Peta creek, creek that springs from the thermal place called "Ochiul Mare" from 1 Mai Spa.	In the analysis of chemical composition of wood fuel can be observed that the environmental impact is given by the combustion gases discharged into the atmosphere from the smoke flue and the ash contained in the wood mass. Another factor may be considered pollutant the exhaust of the flow of heat in the atmosphere that is discharged with the combustion gases. Gas results after the process of oxidation if the combustion is perfect and complete, consist of the following compounds: oxygen, nitrogen, water, carbon dioxide and nitrogen oxides. The gas with pollutant effect discharged at the smoke flue with the highest share content in the combustion phases is carbon dioxide. Carbon dioxide is the result of oxidation of the carbon (24) $C + O_2 \rightarrow CO_2$ (24) Considering gravimetric composition of the wood fuel described in chapter 4.1 we can determine the volume of carbon dioxide obtained after combustion of a mass unit of 1 kg wood fuel. Participation of carbon mass from the wood fuel was considered: m_c=39.3% $0.393 kgC + \frac{0.393}{12} kmolO_2 \rightarrow \frac{0.393}{12} kmolCO_2$ (25) The volume of the carbon dioxide produced by burning a kilogram of wood fuel is: $V_{CO_2} = \frac{0.393}{12} \cdot 22.414 m_N^3\ CO_2 / kg\ fuel$ (26) $V_{CO_2} = 0.734 m_N^3$ CO2 / kg fuel For a residential house the amount of carbon dioxide discharged into the atmosphere over a year is: $V_{hCO_2} = \frac{E_{ht}}{H_i} \cdot V_{CO_2} = \frac{343.9 \cdot 10^9}{14833.4 \cdot 10^3} \cdot 0.734$ $V_{hCO_2} = 17 \cdot 10^3 m_N^3 CO_2 / year$ (27) The entire residential neighborhood produces annually a volume V_{RCO_2} of: $V_{RCO_2} = 200 \cdot V_{hCO_2}$ $V_{RCO_2} = 3400 \cdot 10^3 m_N^3 CO_2 / year$ (28) Due to the low calorific power of the wood fuel, the temperature at which the oxidation occurs are below 1000°C, the nitrogen from the air and fuel composition participate in the oxidation reactions in insignificant quantities. The resulted nitrogen oxides, in the generic

name NOx, can be considered negligible.

The total volume of combustion gas is given by summing the resulted carbon dioxide and the compounds from the air needed for the burning process that don't take place in the oxidation, the water vapors that are in the wood's composition and the one resulted from the oxidation of hydrogen respectively the excess air introduced in the combustion room.

Water resulting from the oxidation of hydrogen from wood V_{SFH_2O} is expressed by the relation (27).

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

$$0.047H_2 + \frac{0.047}{4}kmolO_2 \rightarrow \frac{0.047}{2}kmolH_2O$$

$$V_{SFH_2O} = \frac{0.047}{2}\cdot 22.414 = 0.53m_N^3\ H_2O/kg\ fuel \quad (27)$$

Total volume of water V_{TH_2O} discharged with the combustion gases is given by the relation (30) that is the volume of water from wood and volume of water from the oxidation process of hydrogen.

$$V_{TH_2O} = V_{SFH_2O} + 22.414\frac{w}{18}$$

$$V_{TH_2O} = 0.78m_N^3\ H_2O/kg\ fuel (30)$$

Total volume of gas resulted from the combustion of one kilogram of fuel is given by the relation (31)

$$V_{gt} = V_{CO_2} + V_{O_2} + V_{N_2} + V_{H_2O} \quad (31)$$

where V_{CO_2} is the carbon dioxide volume; V_{O_2} the volume of oxygen in excess; V_{N_2} the volume of nitrogen from the air that enters the combustion chamber and from the fuel; V_{H_2O} the total volume of water from the combustion gases.

$$V_{CO_2} = 0.734m_N^3\ CO_2/kg\ fuel$$

$$V_{O_2} = (Rf - 1)\cdot O_{\min} \quad (32)$$

where O_{min} is the minimum oxygen needed for combustion; Rf is the excess air coefficient for boilers with wood fuel Rf=1.5.

From the oxidation reactions (25) and (28) and subtracting the oxygen from the fuel composition O_{min} is calculated with the relation (33)

$$O_{\min} = \left(\frac{0.393}{12} + \frac{0.047}{4} - \frac{0.341}{32}\right)\cdot 22.414$$

$$O_{\min} = 1.78m_N^3\ O/kg\ fuel \quad (33)$$

The volume of nitrogen from the combustion gases is composed from the nitrogen that is in wood and the

	nitrogen from the air needed for the combustion. $$V_N = \left(\frac{n}{28} + 0.79 \cdot \frac{Rf \cdot O_{\min}}{0.21}\right) \cdot 22.414$$ $$V_N = \left(\frac{0.008}{28} + \frac{0.79 \cdot 1.5 \cdot 0.079}{0.21}\right) \cdot 22.414$$ $$V_N = 10 m_N^3\, N / kg\ fuel \qquad (34)$$ Based on the relation (31) the entire volume of gases is: $$V_{gt} = 0.734 + (1.5 - 1) \cdot 1.78 + 10 + 0.78$$ $$V_{gt} = 12.4 m_N^3 / kg\ fuel \qquad (35)$$ Annually a residential house is discharging a volume of combustion gases at a temperature of 200°C of: $$V_{Ygt} = \frac{E_{hT}}{H_i} \cdot V_{gt} = \frac{343.9 \cdot 10^9}{14833.4 \cdot 10^3} \cdot 12.4$$ $$V_{Ygt} = 2.9 \cdot 10^4 m_N^3 \qquad (36)$$ The entire residential neighborhood discharges annually a volume of: $$V_{RYgt} = V_{Ygt} \cdot 200 = 5.8 \cdot 10^6 m_N^3 \qquad (37)$$ The mass of ash produced by a residential house for each year is: $$m_a = \frac{E_{hT}}{H_i} \cdot a = \frac{343.9 \cdot 10^9}{14833.4 \cdot 10^3} \cdot 0.015$$ $$m_a = 347.7 kg \qquad (38)$$
Economic impact of geothermal systems	Economic impact of systems using solid fuel
For geothermal systems considering all the elements of the system we can assess the cost price of the investment as contained in: • 3000€ secondary heating system; • 1000€ heat exchangers • 500€ submersible pump • 5000€ drilling costs The total cost price of investment for a geothermal system is about 9500€ for a residential house.	The cost price of investment for systems with solid fuel is contained in: • 2000€ secondary heating system; • 6000€ heating station fully equipped • 10000€ the cost price for construction of the space destined to the heating station and wood storage. The total cost price of investment for systems using solid fuel total up to 18000€ for a residential house. Both investment and production costs of a gigajoule of heat is about two times higher in systems with solid fuel in comparison with geothermal systems.

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