Energy, economic and environmental analysis of opened natural healing water source

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Abstract. European´s low carbon economy is the main target in the way of the reducing greenhouse gases at the Earth´s atmosphere. The most promising way is in maximal usage of renewable sources of energy such as geothermal energy, which was in the year 2010 only 1 GWh at the Slovak republic. The paper refers to the detailed analyzation of the opened natural healing water system in the historical spa town Piešťany as one of the most perspective sources of the renewable energy in the Slovak republic primary used for healing procedures. Analysis is based on experimental measurement and numerical simulation of graphite block heat exchanger Korobon which was constructed in the year 1965 and resists highly mineralized water. The main function of this heat exchanger is to cool down the hot natural healing water with average temperature 60 °C to the 37 °C. The biggest impact is in the designing of new heat exchanger with the same quality properties as current one in accordance with the innovation of obsolete energy management at historical spa town. Such as solution allows us to save 5578 cubic meters of ground gas daily, necessary to be used for the same heat generation.

1. Introduction

The low-carbon economy belongs to the one of the biggest EU goal´s which the European commission is looking at. The roadmap suggest that, by 2050, the EU should cut its emissions to 80 % below the year 1990 levels through domestic reductions alone (i.e. rather than relying on international credits). This is in line with EU leader´s commitment to reducing emission by 80 – 95 % by 2050 in the context of similar reductions to be taken by developed countries as a group. To reach this goal, the EU must make continued progress towards a low-carbon society. Clean technologies play an important role. [1]

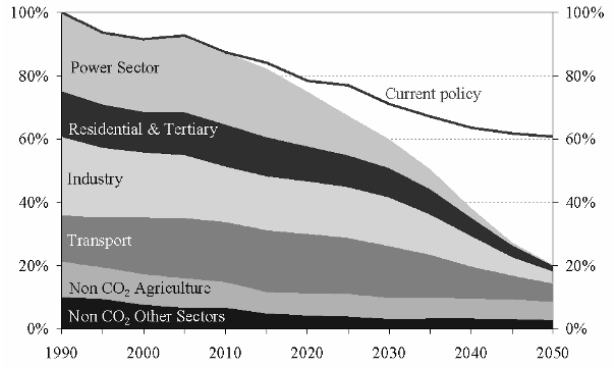

Fig. 1. Possible 80 % cut in greenhouse gas emissions in the EU [2]

1.1. Slovakia – 2020,2050 goals

The aim of Slovak politics is to use renewable sources of energy in ratio to gross final consumption of energy from 6, 7 % in 2005 to 14% till the year 2020. The essential document in relationship with reaching this goal is National action plan for energy from renewable sources of energy, which government granted at 6th of October 2010, government resolution SR c. 677/2010. The resolution goal is to reach 15,3 % from the use of renewable sources of energy in ratio to gross final consumption of energy. The EU wants to decrease the number of greenhouse gases by 20 %, increase the energetic efficiency up to 20 % and use of renewable sources by 20 % till the year 2020 – Table 1. [3]

Table 1 - Estimation of using renewable sources of energy till the year 2020 [4]

Renewable source of energy	Production in year 2002	Production in year 2010	Production in year 2020
	GWh	GWh	GWh
Geothermal energy	**0**	**1**	**40**
Wind energy	0	100	550
Solar energy	0	0	10
Small water power stations	245	350	600
Biomass	153	350	1300
Biological fuels	6	52	500
Sum of energy:	404	853	3000
Water power stations	4924	5000	5300
Sum of energy:	5328	5853	8300

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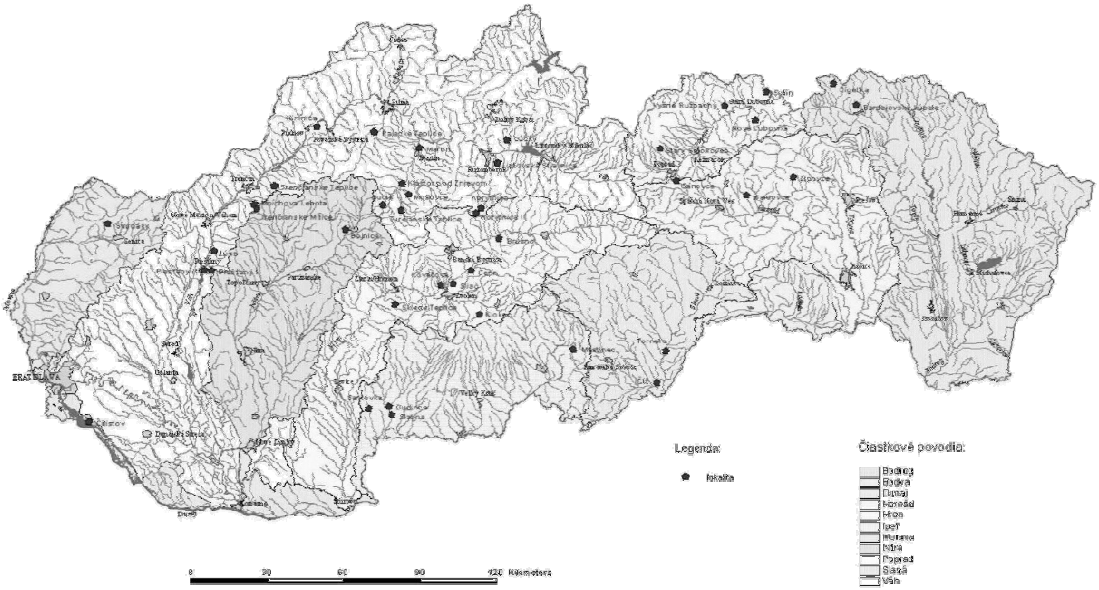

Fig. 2. Natural healing sources at Slovakia [5]

1.2. Natural healing source of water NHS

The natural healing source of water is source of the mineral water, from which was water recognized by the State Spa commission of the Ministry of Health of the Slovak republic as a natural healing water according to the law 538/2005 Z. z. [6]:

According to the conception of geological research and investigation at the territory of Slovak republic from the year 2011, Slovakia has a great energetic potential of the NHS. These renewable sources are split over the whole country and its using has economic and ecological benefits.

A technical exploitable potential of the individual renewable sources is shown at Table 2., where is although shown the energetic potential of the unused renewable sources, which could be used after the introduction of available technologies, breaking administration and ecological barriers. Nowadays we can say, that the most energetic potential has biomass (over 44 %), then the geothermal energy (16, 6%), the solar energy (13, 7%), the waste management (9, 3%), the biological fuels (6, 6%) and the wind energy (1, 6%). [7]

The division of the geothermal sources at Slovakia is: [7]

- Sources with low temperature from 20 °C to 100 °C
- Sources with medium temperature from 100 °C to 150 °C
- Sources with high temperature more than 150 °C

The substantiality is given in ls^{-1} or m^3h^{-1}

1.3. Natural healing source as renewable source of energy in Slovak Republic

Currently the NHS energy is used at almost 40 locations and next 26 are considered to be new source of renewable energy (Fig. 2.). At the depth 1000 m under the therian level, should has the natural healing water temperature around θ = 40 °C, this fact influence the surface temperature. The water is getting into this depth primary by curtain from mountain ridges after rainfall. In Liptovský Mikuláš region reach the limestone mountains the depth around two kilometers and the water is naturally heated to the temperature θ = 60 – 70 °C. [8]

1.4. Potential natural healing source of water at Slovak Republic

A Spa area is declared town territory or the part of town territory, on which are located the natural healing water sources, the natural healing spa, the healing spa and other devices necessary for providing healing procedures. [5]

A Spa territory is comprehensive territory at the spa area, which size is defined in the statute of the spa area. At the spa area is applied protection of a spa regime. [5]

The regulation No. 446/2006 Z.z. issued by the Slovak government were assigned statutes of the spa area, which can be seen in Table 2.2. with the resolution number of the Slovak government. At the Slovak Republic only this places are allowed to provide healing procedures by using natural healing sources. [5]

Table 2 – Technical exploitable potential of individual renewable sources [7]

Name of renewable source	Technical exploitable potential		Present using of source		Unused energetic potential	
	TJ/r	GWh/r	TJ/r	GWh/r	TJ/r	GWh/r
Geothermal energy	**22 680**	**6 300**	**1 224**	**240**	**24 456**	**5 960**
Wind energy	2 178	605	0	0	2 178	605
Solar energy	18 720	5 200	25	7	18 695	5 193
Small water power stations	3 722	1 034	727	202	2 995	832
Biomass	60 458	16 794	11 491	3 192	48 967	13 602
Waste management	12 726	3 535	4 504	1 251	8 222	2 284
Biological fuels	9 000	2 500	1 188	330	7 812	2 170
Sum of energy:	129 484	35 968	19 159	5 222	113 325	30 646
Water power stations	23 785	6 607	18 335	5 093	5 450	1 514
Sum of energy:	153 269	42 575	37 494	10 315	118 775	32 160

2. Piešťany – opened natural healing source of water

For the purpose of analysis, was chosen a small spa town Piešťany, located at the west side of Slovakia, 80 km from the capital city Bratislava (Fig.3.) Because of its good position from the Vienna International airport Schwechat– road distance 160 km and from Bratislava International airport – road distance 80 km, is visiting yearly by thousands of visitors and people willing to be curate.

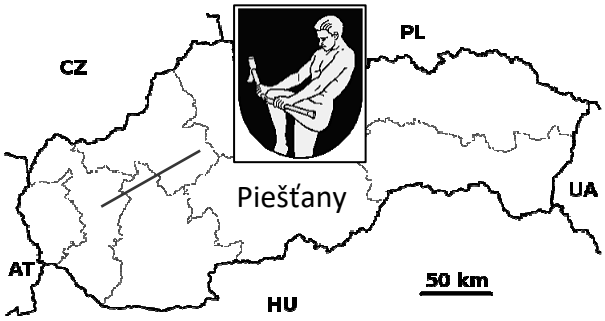

Fig. 3. Location of Spa town Piešťany, Slovakia

2.1. Collection of natural healing water at Piešťany health spa

Collection of the natural healing water for the Balneotherapy departments is located at observed from historical point of view significant locations, where were by the long-term analysis detected the healing effects on a human organism. Mostly they are the natural seepage of the natural healing water source, which are collected and by the technological equipment transported to the Balneotherapy departments (Fig. 4.).

Analyzation of the natural healing sources at the Slovak Health Spa a.s. Piešťany has geological character, which describes the existing natural healing water system. This section is including in this diploma thesis as it is considered to be initial data for the elaboration complex analysis of the Balneotherapy. The analysis provide information about the temperature and the flow rate of individual natural healing water source, which is affected by the level of recipient and its flow rate regulation – Table 3.

Table 3. Wells and drills at Spa Island

Source of NHS water		Max. enabled collection of NHS water	Temperature of NHS from long-term point of view	Depth
		[l/s]	[°C]	[m]
Drills	V1	4,1	62,6 - 66,7	54,3
	V4a	8,0	64,4 - 66,5	54,0
	V8	6,2	62,2 - 67,0	55,0
Wells	Adam Trajan	13,5	60,8 - 62,5	16,0
Total		31,8		

Fig. 4. Image representation of natural healing water sources springing into the balneotherapy departments from the left side Thermia Palace, Irma, Napoleon spa and on the left side Pro Pátria (Source: Wall painting at Irma)

2.2. Accumulation station

Due to the fact that the natural healing water has temperature cca. 65 °C at source, is useless for the healing procedures at the Balneotherapy departments and it is necessary to mixed it with the cooled NHS water. Mixing of the NHS water with another water e.g. from common well is not possible due to its mineral composition which will discard healing proposition of this water and cause its coloring. For this reason it is necessary to cooled down the NHS water collected from the natural healing water source.

From the source is the NHS water flow-through gravitationally collected at lower part of the accumulation station, where with the help of pumps is pressed into the opened distribution system. To secure required amount of the NHS in consideration of nonlinear requirement, there are situated horizontal tanks for the accumulation of at NHS at accumulation station. Nowadays Spa Piešťany owned 4pc. of an horizontal tanks for hot NHS and 6 pc. for cold NHS. The accumulation station has the biggest impact as concerning energetic, environmental and ecological point of view. Analysis of this object is the most important part, because all the Balneotherapy departments are supplied and depended on its operation.

Scheme 3.6. shows distribution of the natural healing water from drills V1,V4a,V8 and well Adam Trajan in bottom right corner at the accumulation station. The amount of water is on the base of the monitoring system of the Slovak Ministry of Health monitored and recorded. Average temperature of the natural healing water which is pumped into the water distribution system is 67 °C, which was obtained from long-term measurement. Part of the NHS water is flowing directly to the hot water distributor (marked with red color), from

where is flowing into the Balneotherapy departments, second part is flowing into the block graphite heat exchanger Korobon, where is cooled down to temperature ccs. 24 °C and flowing to the cooled water distributor (marked with green color), from where is flowing to the Balneotherapy departments. Analysis of block graphite heat exchanger is evaluated in next section. The distributor of hot NHS water separate partially amount of NHS hot water for the hot NHS water storage tanks, where is stored at temperature cca. 67 °C and pressure 1,8 bar. The cold NHS distributor separate partially amount of the NHS cooled water for the cooled NHS water storage tanks, where is stored at temperature cca. 24 °C and pressure 2,4 bar. The pressure in the storage tanks is provided with the help of air collected from the compressor at the pressure air tanks (marked with blue color). In the case of high demand of water it is possible to use this stored water in the distribution system.

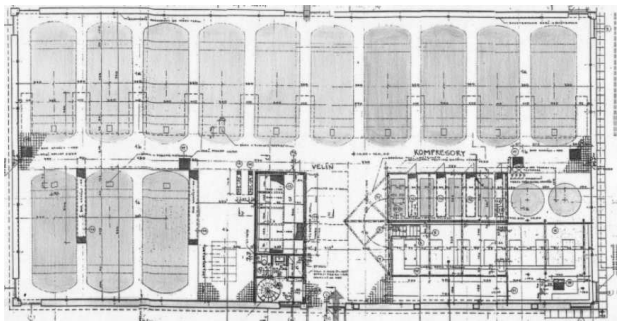

Fig. 5. Scheme of current accumulation station

3. Korobon - graphite heat exchanger

For ensuring the operation of the Balnotherapy in the SLKP a.s., the opened natural healing water system is complete with the distribution of cooled NHS water, which is prepared at the Korobon graphite block heat exchanger (see Scheme 3.10.). The Korobon heat exchangers is special atypical heat exchanger situated at the accumulation station. It was constructed in 1965 in the Germany Democratic republic by company VEB ELEKTROCHEMISCHES KOMBINAT BITTERFIELD under the name KAMMER – WÄRMEUBERTRAGER K20/20 – KOROBON 10302 (Picture 3.24.).

Basic parameters:

- Number of units: 12
- Heat transfer surface area: 22 m^2 / unit
- Height: 1,63 m
- Length: 1,565 m
- Width: 0,440 m
- Power of one unit: 112 kW
- Power of heat exchanger: 1 344 kW

Fig. 6. Korobon block graphite heat exchanger

3.1. Temperature and flow rate experimental measurement

The experimental measurement of the NHS water at the Korobon graphite block heat exchanger was provided by the Comet data logger from 20.11.2016 to 11.03.2017 and was hold on the pipelines of the hot natural healing water (red color in scheme), the cooled natural healing water (green color in scheme), the hot service water (yellow color in scheme), the cold service water (blue color in the scheme) (Fig. 7.)

After an consultation and technical decision there were four temperature sensors placed, one on each pipelines (see Fig. 7.). All sensors were insulated from outer influences with polystyrene th. = 40 mm, and the heat transfer area was increased with the help of aluminum foil in shape of U.

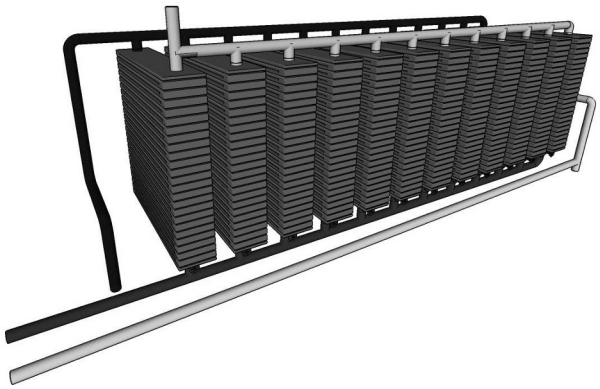

Fig. 7. Korobon heat exchanger scheme

Chart 1. – Temperature measurement of the cold service water, shows that more than 95 % of operation time is the temperature interval of cold service water (14,7 °C – 18,0 °C) and will be input data for the experimental solution. Temperature data from interval (18,0 °C – 19,3 °C) is less than 5 % of the operation time and could be considered as an error in measurement,

caused by outer influences, such as manual control of sensors.

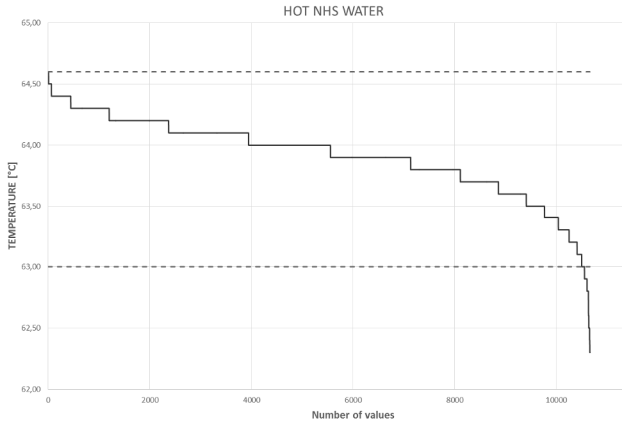

Chart 1. Dependence of temperature and number of values – hot NHS water

Chart 2.. – Temperature measurement of the hot natural healing water, is clear that more than 99 % of operation time is the temperature interval (63,0 °C – 64,6 °C), which will be input data for the experimental solution. The temperature interval (62,3 °C – 63,0 °C) is less than 1 % of operation time and could be considerate as an error in measurement caused by outer influences, such as manual control of sensor.

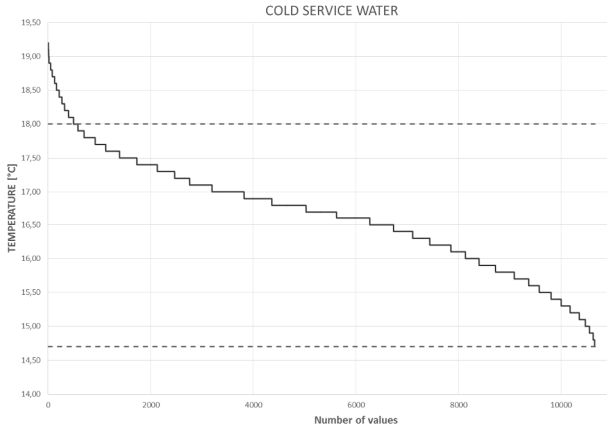

Chart 2. Dependence of temperature and number of values – cold service water

Chart 4. – shows dependence of the service water measured values and the number of data, analyzation of the flow rate was consulted with the project manager of SLKP a.s., and after technical revision it could be stated that the flow rate during the operation of the Balneotherapy is in interval (1 m^3/15 min – 13 m^3/15 min), which is 95,2 % of the operation time. Values outside interval are impossible to obtain and could be considered as an error in measurement, caused by human factor. This error is 4,8 % of operation time, which is from technical point of view acceptable.

Chart 5. – shows dependence of the hot natural healing water measured values and the number of data, analyzation of the flow rate was consulted with the project manager of SLKP a.s., and after technical revision it could be stated that the flow rate during the operation of Balneotherapy is in interval (1 m^3/15 min – 13 m^3/15 min), which is 96,85 % of operation time. Values outside interval are impossible to obtain and could be considered as an error in measurement, caused by human factor. This error is 3,14 % of operation time, which is from technical point of view acceptable.

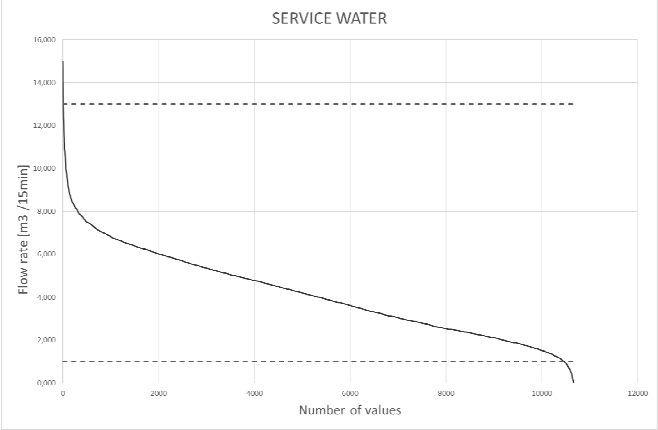

Chart 4. Service water flow rate measurement dependent on number of values

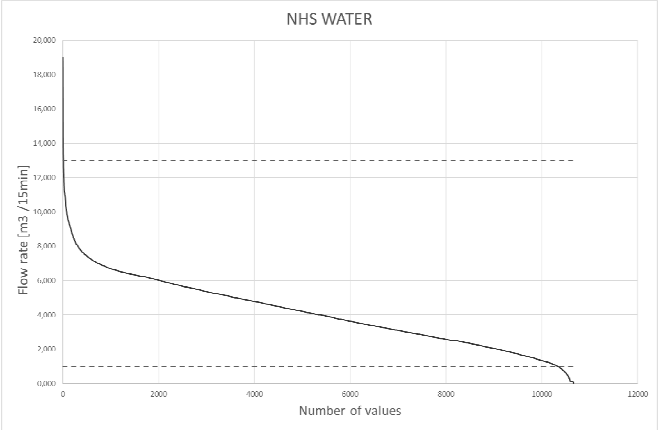

Chart 5. NHS water flow rate measurement dependent on number of values

3.2. Simplified computer simulation of Korobon in ANSYS software

The computational analysis is provided on one unit of the Korobon heat exchanger, which was due to the academic license of the ANSYS Fluent software restriction in the amount of the computational ceils simplified. Thirdly the solution was evaluated in the ANSYS Fluent software with the boundary condition, which were obtained from the real operation of the Korobon heat exchanger:

- Hot inlet temperature: 67 °C
- Cold inlet temperature: 18 °C
- Hot water flow rate: 13,03 l/s
- Cold water flow rate: 13,3 l/s

The graphical solution gives us view on the process at the Korbon heat exchanger unit during the operation and future possibility to determine critical states. A validation of calculated data is provided by thermography picture of the Korobon heat exchanger generated at the time of the boundary conditions (Fig. 8.)

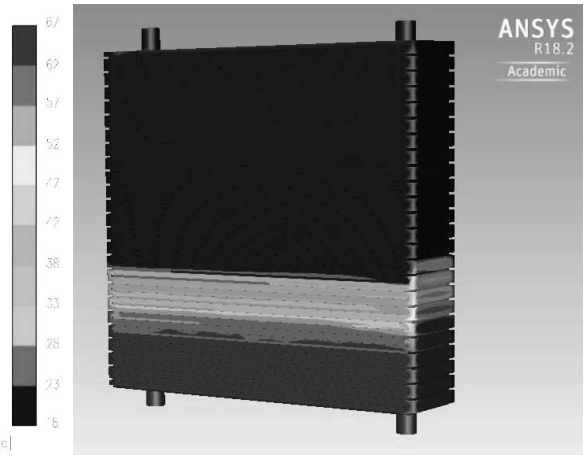

Fig. 8. Solution of thermal field in Korobon unit evaluate in ANSYS Fluent

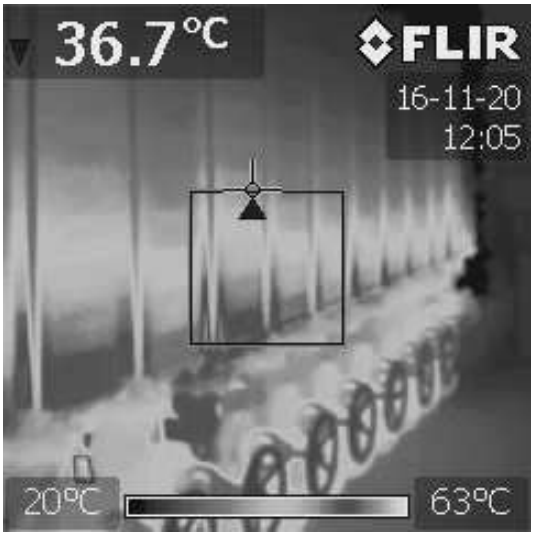

Fig. 9. Thermography picture of Korobon heat exchanger

Based on the measured data, simulation and analysis it is possible to say that for operation of the Balnotherapy and other collection places, is necessary to accumulate 731,64 m^3/day of the hot NHS water and 621,69 m^3/day of the cooled NHS water. Current accumulation system – the Korobon heat exchanger is able to accumulate 489,26 m3/day of the cooled NHS water, which is less than total amount of the cooled NHS water daily used in operation of the Balneotherapy. This water amount difference is currently solved by the accumulation of cooled and hot NHS water in the accumulation tanks from where is transporting to the Balneotherapy in case of higher water amount demand.

4. Experimental solution of opened natural healing water system

The experimental solution in the vision of the accumulation station reconstruction at the Slovak Health Spa Piešťany a.s., within which the safety operation of the Balneotherapy should be increased, with the maximum usage of the NHS water and the hot service water energetic potential at the same time. This solution will leads to energy costs savings at operation of the Balneotherapy. For increasing the NHS cooled water amount with the temperature cca. 24 °C, will be flanged next heat exchangers at accumulation station. The number of heat exchanger will depend on the type of heat exchanger and expert decision of manufacturers. New heat exchangers will be situated at lower part of the accumulation station on concrete pads, on which are currently situated pumps and will be in parallel connection with the existing Korobon heat exchanger. Due to the fact of sedimentation the design of new heat exchanger is based on the assumption to be 100 % backup of the existing Korobon heat exchanger (Fig. 9.) The most important criteria in the design of accumulation station reconstruction was the ability of heat changer material to resist highly mineralized natural healing water. Due to this fact was chosen as the best material for future operation carbon fibers composite, similar to the existing one, which has been tested as a prototype for more than 50 years. The best variant was elaborated with the help of SGL Group Company, which is designer of the original placed block graphite heat exchanger Korobon. Technical specification is designed in the way of adding next 12 DIABON graphite groove heat exchangers parallel to the existing Korobon heat exchanger (Fig.10.).

Customer:	Slovenske Liecebne Piestany				SGL GROUP THE CARBON COMPANY Prozess Technology		
Project:	12 units in parallel						
Date:	21.12.2017						
Media:	System 1 Media 1:	Water			System 2 Media 2:	Water	
Process Data	Symbol	Steam In	Liquid out	Unit	Symbol		Unit
Mass flow per unit	m_1	0	3900	kg/h	m_2	3990	kg/h
Volume flow	V_1	0	3,91	m^3/h	V_2	4,0	m^3/h
Temperature IN	T_{E1}	67		°C	T_{E2}	14	°C
Temperature OUT	T_{A1}	21		°C	T_{A2}	58	°C
Pressure (abs.)	p_1	2,5		bar	p_2	4,3	bar
Max. allowed pressure drop	Δp_{1zul}	0,5		bar	Δp_{2zul}	0,5	bar
Calc. pressure drop	Δp_1	0,07		bar	Δp_2	0,087	bar
Fouling factor	R_1	0		m^2K/W	R_2	0	m^2K/W
Physical properties		Steam	Liquid				
Density	ζ_1 (Rho$_1$)	0	998	kg/m^3	ζ_2 (Rho$_2$)	998	kg/m^3
Spec. heat capacity	c_{p1}	0	4180	J/kgK	c_{p2}	4180	J/kgK
Heat conductivity	λ_1 (Lambda$_1$)	0	0,643	W/mK	λ_2 (Lambda$_2$)	0,643	W/mK
Viscosity	η_1	0,000554	0,000554	kg/ms	η_2	0,00055	kg/ms
Heat Duty	208,3 kW						
MTD	8 K						
Required Area	42,2 m2						
Actual Area	21,5 m2						
Overdesign	-49%						
Choosen apparatus	GHX-H-40-1.1						
Dimensions	1510 x 470 x 1330 mm						
Weight	ca.1164 kg						
Process Volume	System 1	136	l		System 2	114 l	
Nozzle Diameter	N3; N4		DN 80		N1; N2	DN 80	

Fig.10. Graphite block heat exchanger – SGL Group

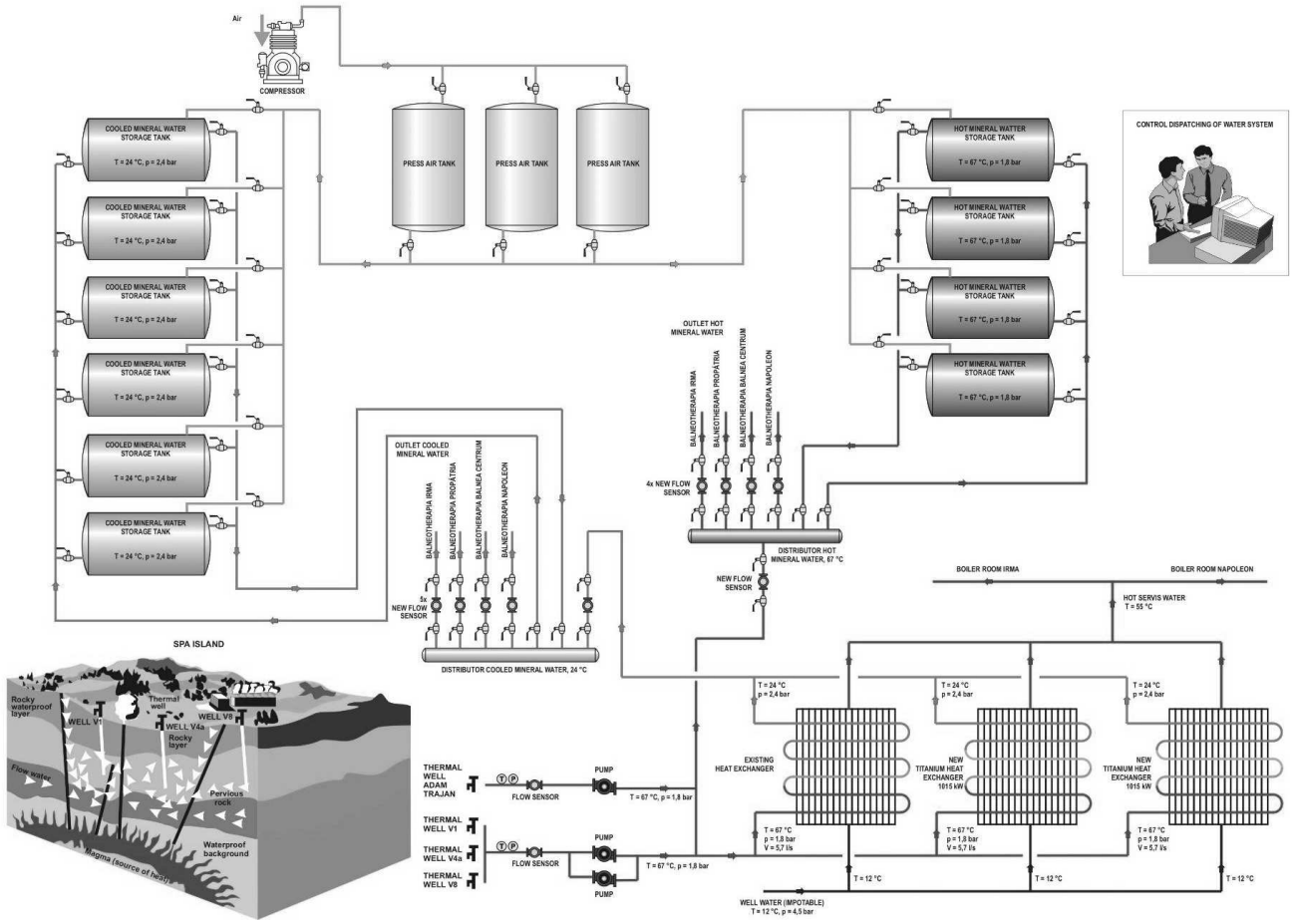

Fig. 11. Scheme of accumulation station – designed solution

5. Ecology and economic evaluation

The economic evaluation is based on compartment of the heat boiler room Balnea Centre with performance 9,98 MWh and the designed opened NHS water system – Table 4.4. and Table 4.5

Table 4. Economic evaluation of the heat boiler room in Balnea Centre

The heat boiler room Balnea Centre - performance 9,98 MWh		
Measured amount of consumed gas in July 2015	m^3	40 918
Average amount of consumed gas per one day	m^3	1 320
Costs of gas in July 2015	€	19 780
Price for m^3	€/m^3	0,4834
Calorific value of gas in July 2015	kWh / m^3	9,685
Measured amount of energy in gas July 2015	kWh	396 291
Measured amount of energy per one day	kWh	12 784
Measured amount of consumed gas per year 2015	m^3	1 614 815

Table 5. Total savings per one day

Amount of green house gases	The heat boiler Balnea Centre	Korobon	Diabon	Korobon + Diabon
	kg/day	kg/day	kg/day	kg/day
TZL	0,10031515	0,00640270	0,00727227	0,01367497
SO2 / SOx	0,01203772	0,00076832	0,00087267	0,00164098
CO	1,95614453	0,12485264	0,14180917	0,26666181
TOC	0,78998157	0,05042127	0,05726910	0,10769036
Amount of used NHS water per one day	kWh	**25293,61**	**28728,79**	**54022,40**
Amount of saved gas	m3	2612	2966	5578
Total savings per one day	€	1262	1434	2696

6. Conclusion

Life environment is source of the all living species on the Earth. To ensure its quality and protection against the human factor the European Union accept several goals, such as the low-carbon economy, which should decrease amount of the Green House gases in the Europe by increasing the use of renewable sources.

From applicability point of view the most uncommon renewable source in the Slovak republic is the natural healing source energy, which currently we are using only for healing purposes. Energy stored in the NHS systems due to its relatively high temperature has big energy potential, which can beneficially influence the economic and environmental situation in the Slovak republic.

The main goal of this analysis is to design the new technological devices to increase generation of the cooled NHS water, which will cover current insufficiency and allow the SLKP a.s. to provide expansion of the Balneotherapy. For this purpose were elaborated four variants and with the help of multiple-criteria decision chosen the one which will from energy, economic and environmental point of view be the most efficient.

The overall result is in form of the experimental calculation of the new technological devices connected to the existing opened NHS system. Firstly, it was proven, that decreasing the temperature of the cooled NHS water will leads to increasing the amount of used hot NHS water distributed directly from water source in the Balneotherapy departments. Secondly, new design technological devices will increase the amount of the saved gas necessary to heat water in the Balneotherapy departments and therefore help to the SLKP a.s. to fulfil the European Union low-carbon economy.

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