INVESTIGATION OF INDUSTRIAL WASTE HEAT STORAGE IN SHALLOW POROUS SYSTEMS

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Abstract
In our research we investigated the potential of heat storage under shallow porous conditions. In this case, the thermal energy storage is performed by an aquifer thermal energy storage (ATES), which is a subsurface saturated natural rock layer. This type of thermal storage can have different effects on both groundwater and deep aquifers, and therefore we need to know the behaviour of ATES systems. The modelling was carried out using a module of the Groundwater Modelling System (GMS). The main objective of our waste heat storage simulation studies was to develop an alternative to this type of thermal storage for industrial facilities with large amounts of waste heat.

Keywords: *waste heat, ATES, porous system*

1. Introduction

Energy demand is generally not constant, nor is energy supply (e.g. solar energy), and these facts are pushing us to find more efficient and economical ways to use energy, not only in the areas of energy production, transmission, distribution and consumption, but also in the field of Energy Storage (ES) (Kun, 2013).

One way of solving this problem is to use thermal storage, which can provide a buffer to smooth out fluctuations in energy supply and demand. This technology can reduce the various shortcomings of renewable energy technologies by storing a surplus of renewable energy during high production intervals to compensate for any shortfall during low production intervals, especially for wind and solar power, whose available energy production varies at different hours. To do this, energy storage systems need to reflect energy demand cycles, with short, medium or long-term (seasonal) storage capacity (Nielsen, 2003). Thermal energy storage (TES), as a seasonal storage system, can store excess thermal energy in summer for use in winter, contributing significantly to improving energy use efficiency, with the main advantage of using thermal energy (heat and cold) that would otherwise be lost because it was available at the wrong place at the wrong time. This method of energy storage can also significantly reduce the use of fossil fuels and the emission of greenhouse gases and air pollutants (such as CO_2 , SO_x and NO_x).

2. Heat storage options

Today, the use of renewable energy sources plays a crucial role in the global climate change and energy crisis. In 2021, the day of overconsumption fell on 29 July, which means that we have used up the Earth's resources in about seven months, which forces us to act on the efficient use, storage and distribution of energy.

In the case of energy demand and, in the case of renewables, energy production, we are not talking about a constant, constant value over time, but about a quantity of energy that changes over time. One way to solve this problem could be to use thermal energy storage, which can provide a buffer to bridge the fluctuation between energy use and production, and thus follow the cyclical energy use in the short, medium and long term (Miklós, 2018).

2.1. Thermal energy storage

This form of energy storage is the temporary storage of high and low temperature thermal energy for later use (Figure 1) (Dinc and Rosen, 2011).

Downstream uses can include heating, cooling, melting, liquefaction and evaporation.

Types of thermal energy storage:

- Stored energy by temperature
  - Low temperature energy storage,
  - High temperature energy storage,
- According to storage period:
  - Short term,
  - Long-term,
- According to the state of the energy-consuming substance
  - Latent heat storage,
  - Thermochemical heat storage,
  - Good thermal conductivity of heat conducting materials.

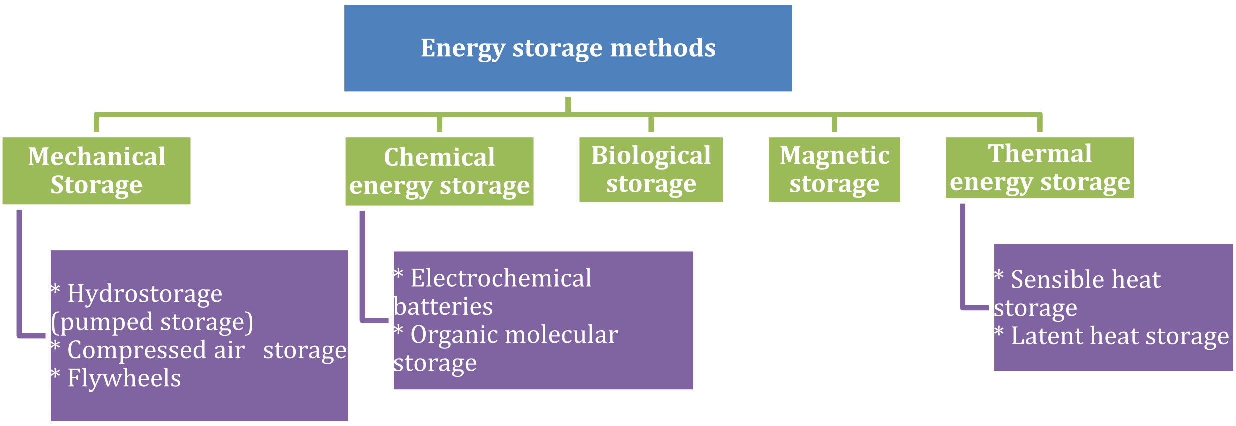

Figure 1. *Classification of energy storage methods (Dinc and Rosen, 2011)*

In thermochemical heat storage, chemical substances are used where the chemical substance can absorb or release large amounts of heat while chemical bonds are broken down or formed.

In the case of heat storage with good thermal conductivity, the temperature of the storage medium is changed and a change in the internal energy of the medium is induced, without phase transformation.

Latent heat storage exploits the fact that some materials undergo a phase transition without changing their temperature. These materials can store or release large amounts of heat during their phase transformation.

2.2. Subsurface heat storage

Subsurface heat storage is also provided by nature, as the subsurface medium passively stores heat due to seasonal changes. At a depth of 10 to 15 metres, the temperature of the soil and groundwater is not affected by weathering, so the temperature of the subsurface is higher in winter and lower in summer than at the surface. Consequently, soil and groundwater can be considered as a heat storage medium.

Different heat recovery systems are often used for both cooling and heating depending on the season. This means that the extracted heat is returned to the ground in summer, so that the soil and groundwater form a heat storage system, which optimally creates a thermal equilibrium. If this thermal equilibrium is upset (i.e. heating demand is lower or higher than cooling demand), an additional heat storage system is needed. Systems that provide heat storage in a natural subsurface medium are called Underground Thermal Energy Storage (UTES) systems.

Underground Thermal Energy Storage Systems	**Storage temperature**	* Low-temperature system * High-temperature system
	Storage purpose	* Heating * Cooling * Combined
	Application	* Residential * Commercial * Industrial
	Storage technology	* Aquifer thermal energy storage (ATES) * Borehole thermal energy storage (BTES) * Cavern thermal energy storage (CTES) * Pit storage * Water tank

Figure 2. *Classification of UTES systems (Kun, 2013)*

The advantages of these systems can be summarised as follows:

- large energy reserves can be stored naturally and used later for a variety of purposes (cooling, heating),
- low running costs that generate profits in the long term,
- environmentally friendly technology,
- allows for the further exploitation of abandoned and decommissioned wells.

Underground thermal storage systems can be classified according to the following criteria:

- stored temperature (low, high),
- purpose of heat storage (cooling, heating, combined),
- heat storage technology (open, closed, other),
- application, place of use (residential, public, industrial).

2.3. Aquifer thermal energy storage (ATES) system

A schematic diagram of subsurface heat storage systems is shown in Figure 3. The applicability of these systems is essentially determined by the area and the thickness of the layer, but the storage capacity is orders of magnitude smaller than the volume of the aquifer. Other important parameters for the aquifer are the porosity and the hydraulic conductivity.

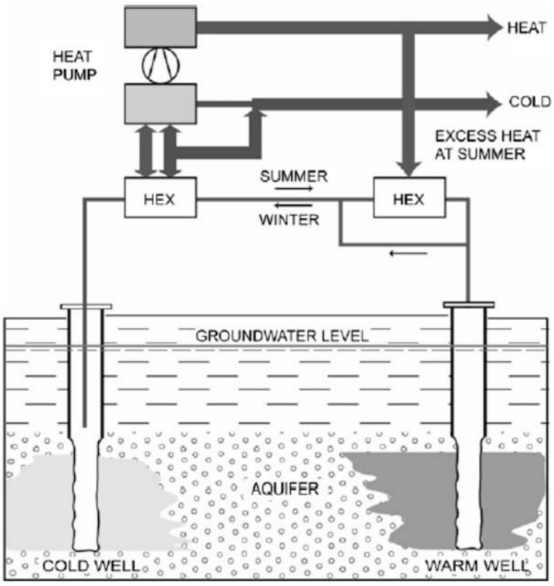

Figure 3. *ATES configuration (Bridger and Allen, 2010)*

The thermal conditions of the aquifer also influence the heat capacity. An important parameter is thermal conductivity, which affects the amount of heat that can be stored at a given gradient. The thermal conductivity of porous aquifer systems does not vary over a wide range. Basically, subsurface media are good insulators. Therefore, thermal conductivity is a secondary parameter in determining the heat storage capacity.

Site-specific hydrogeological parameters can be determined by drilling and test pumping studies.

Other parameters to be defined:

- stratigraphy,
- mesh distribution,
- distribution of cracked zones,
- depth of the water tax, boundary conditions, water tax limits,
- storage factor,
- vertical water movement rate,
- degree of consolidation,

- geothermal gradient,
- water level at rest,
- direction and rate of natural water flow,
- hydrochemical properties.

3. Modelling studies

Modelling can be used for a variety of reasons, but in the case of heat storage, the main concern is to test the functionality of a given system. By examining different well layouts, temperatures and yield data, we can determine the optimal parameters at which a system will operate economically (Hecht-Mendez et al., 2010).

The modelling gives two main types of results:

- Impact of a thermal storage system on groundwater (determining water level rises and falls);
- Delimitation of the heat affected zone.

The modelling environment used is the Groundwater Modelling System 10.3 software package, which includes the MT3DMS module, which is capable of heat transport modelling.

In our work, we have investigated heat storage options where we believe there is a need. Our chosen sample area is the area around Tiszaújváros, where the industrial park generates a large amount of waste heat. The area is characterised by the fact that waste heat from the industrial park is discharged into the Tisza, causing changes in the river ecosystem. Our aim is to investigate whether it is possible to store these large amounts of heat in the geological setting of the Tiszaújváros area. Our study relies on computer simulation to model the extent to which the injection of waste heat into the groundwater and its extraction alters the natural water flow regime and the efficiency of this heat storage.

The geological structure is characterised by the presence of a sedimentary, porous system, which may be suitable for the injection of heat by a mediating medium (water). The presence of a sedimentary environment is confirmed by the hydrogeological log of thermal wells in the area. The obtained hydrogeological logs refer to the wells K-50, K-75, K-77 and K-123 in the area of Tiszaújváros (appendix). Based on the hydrogeological logs a geological model is built. After construction" is a better expression, we will simulate the groundwater flow, taking into account the water levels and withdrawals at rest. The aim of our research is to determine the water level changes caused by the planned water withdrawals and injection. After building the hydrogeological model, we aim to build a heat transport model that will show the temperature conditions in the aquifer that are affected by this heat storage. These investigations will be complemented by scenario studies for different yield and temperature conditions.

MODFLOW is able to incorporate spatially varying aquifer properties, geological stratification and production/injection wells over multiple intervals, assuming constant discharge density and full saturation. Prior to setting up the MT3DMS simulation, a MODFLOW solution with hydrodynamic properties specific to the area must exist, which is the basis for the flow field of the transport simulation.

The injection and production cycle is repeated for 25 years. During the simulations, monitoring points are inserted every 10 meters at the location of the production and monitoring wells to monitor hydraulic pressure and temperature.

The following experimental simulation scenarios were carried out:

- All wells are dual function, with alternating injection and production every six months. Injects water with an initial temperature of 333.15 K (60 °C) for 6 months at a yield of 1500 m^3 /day and produces 2000 m^3 /day for 6 months per year.

- The use of a well system, where 2 wells inject water at a constant yield of 1500 m^3 /day at 333.15 K (60 °C) for 6 months, and 2 other wells produce 2000 m^3 /day per year for 6 months.

4. Results of the modelling

Scenario 1

Figure 4 shows the water level changes resulting from 25 years of operation of seasonal ATES dual function wells. The varying hydraulic heads increase over the injection period in the area adjacent to the well in which the still water level is 11.35 m above initial water level and the injection affected area is 400 m. The maximum observed water level is 95.95 masl.

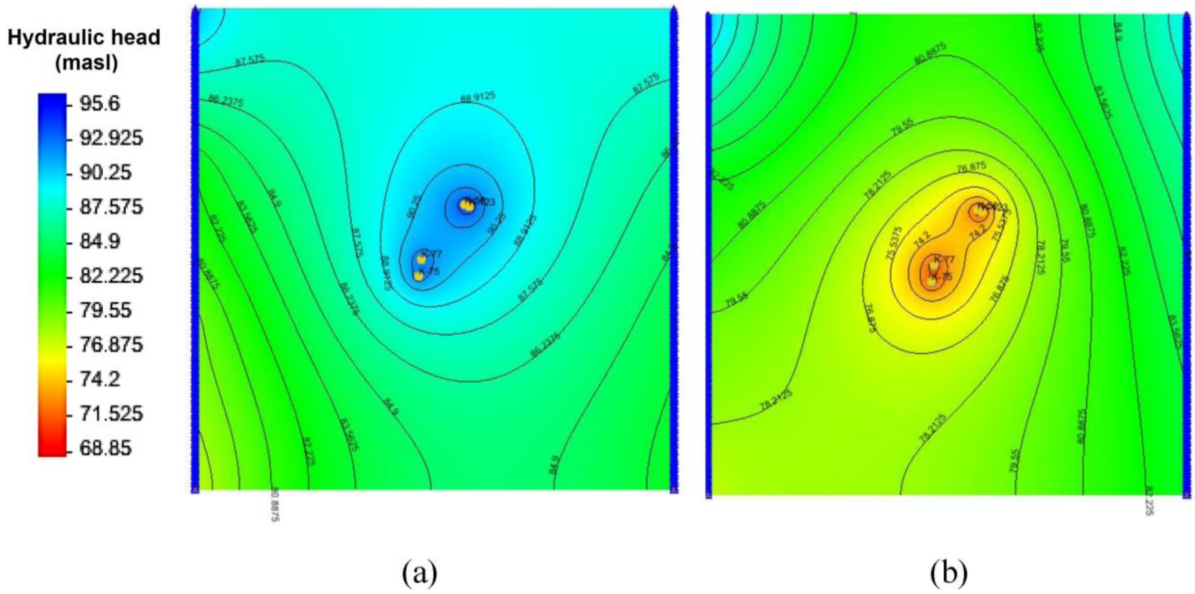

Figure 4. *Water level changes under the first scenario a) after the injection period and b) after the production period (at the end of year 25).*

The flow direction then changes towards the production wells, creating a direct reach of about 450 m, with a maximum difference between initial and production water levels of 15.13 m and a lowest observed water level of 69.13 mBf.

The result of the heat transfer model is shown in Figure 5. The heat injection at wells K-50 and K-123 together creates a heat flux of about 90 m in diameter, while K-75 and K-77 separately create a 60 m diameter heat flux. Once the extraction period has started, the heat vents will retreat into the wells. In the area around K-50 and K-123, heat retreat is faster. On the other hand, the hot water from the injection period of K-75 and K-77 always accumulates around the wells, which means that there is always a residual amount of heat in the aquifer around wells K-75 and K-77.

Second scenario

For the second case study, changes in observed hydraulic pressure results from 25 years of operation are shown in Figure 6. Injection wells K-50 and K-123 are operated at a constant yield of 1500 m^3 /day, while production wells K-75 and K-77 are operated at a constant yield of 2000 m3 /day for 6-6 months per year. During the production period, the observed hydraulic heads are increased, resulting in a direct reach of approximately 190 m. Thereafter, the production period begins, producing a direct reach of approximately 170 meters, and the impact on water levels decreases as the production wells K-50 and K-123 progress towards production wells K-75 and K-50.

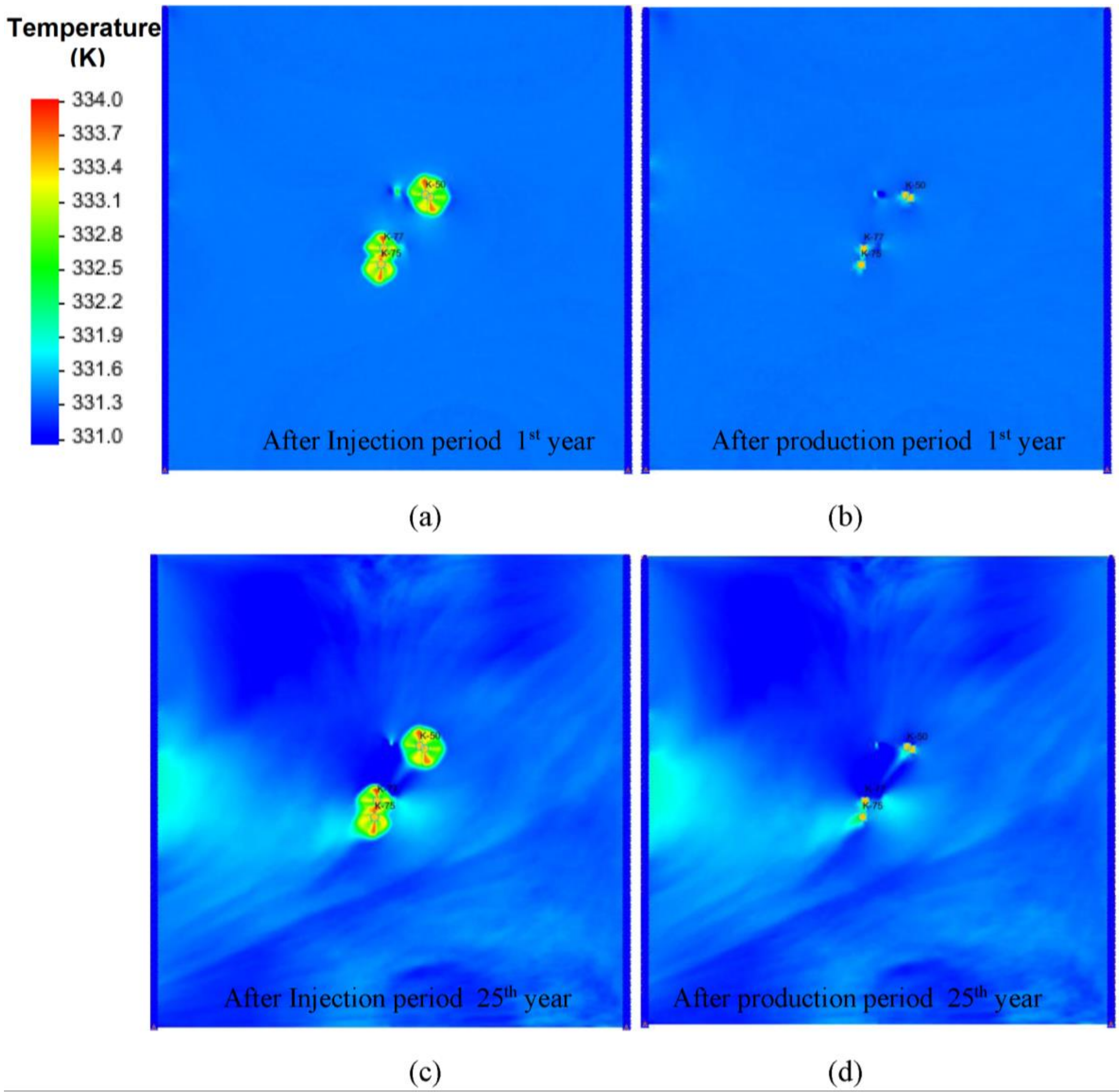

Figure 5. *For the first scenario, the temperature distributions at different times are shown for a) the last day of the first injection period, b) the last day of the first production period, c) the last day of the 25th year injection period, and d) the last day of the last annual production period.*

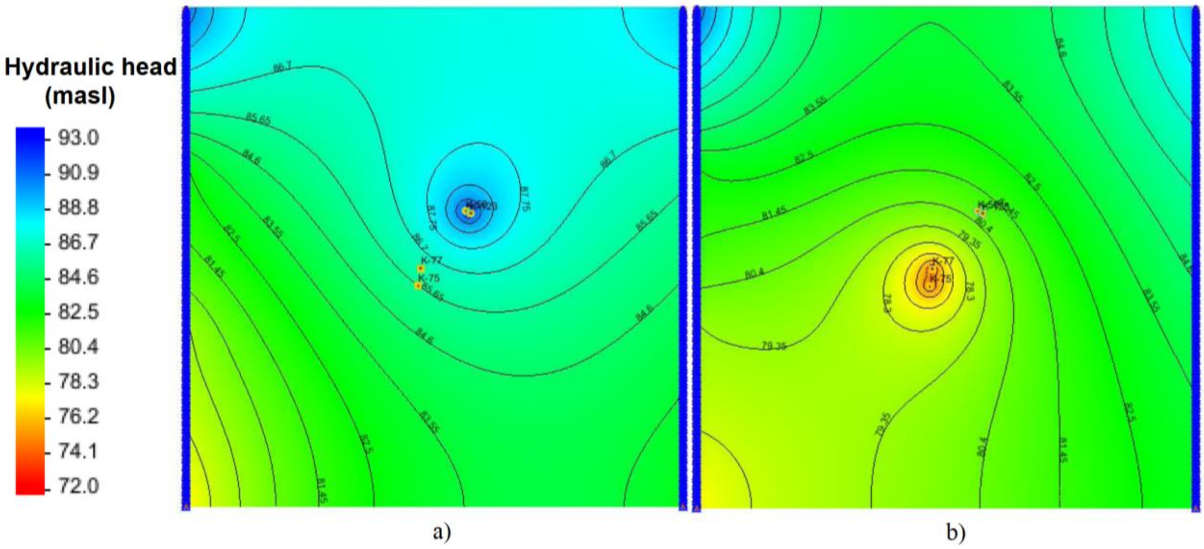

Figure 6. *Water level changes under the second scenario a) after the injection period and b) after the production period (at the end of year 25).*

The results of the heat transfer model are shown in Figure 7. The heat distribution in injection wells K-50 and K-123 is about 90 m in diameter at the end of the first injection cycle, and is shown to reach production well K-77 in year 4 and K-75 in year 6. Thereafter, the temperature increases year by year for both wells.

5. Summary

Using three-dimensional heat transfer simulation studies, we identified the parameters that most influence the thermal behaviour of the ATES system, namely:

1. the distance between the injection well and the production wells;
2. the characteristics of the area where the production well(s) will be located;
3. injection and production yields for each well, as well as hydraulic and thermal parameters.

Simulation test results show that the heat transport models are relatively sensitive to the maturity of the hydraulic conductivity, which will be supported by parameter sensitivity studies in the future. Parameters such as effective porosity and hydrodynamic dispersivity are likely to have a moderate effect. From the simulations, it appears that higher injection volume and higher temperature, as well as longer injection duration, are the parameters that may contribute to higher temperatures and higher heat storage capacities in the layer.

The simulation experiments in this study show that the two simulated heat transport models can correctly predict the effects of heat transport and storage in ATES systems, even when the differences between the injected thermal water and ambient temperatures are small. Nevertheless, the simulation models can be used to investigate the efficiency and heat production of ATES systems in different hydrogeological environments, which can be a great help in the future in the process of designing and constructing a system.

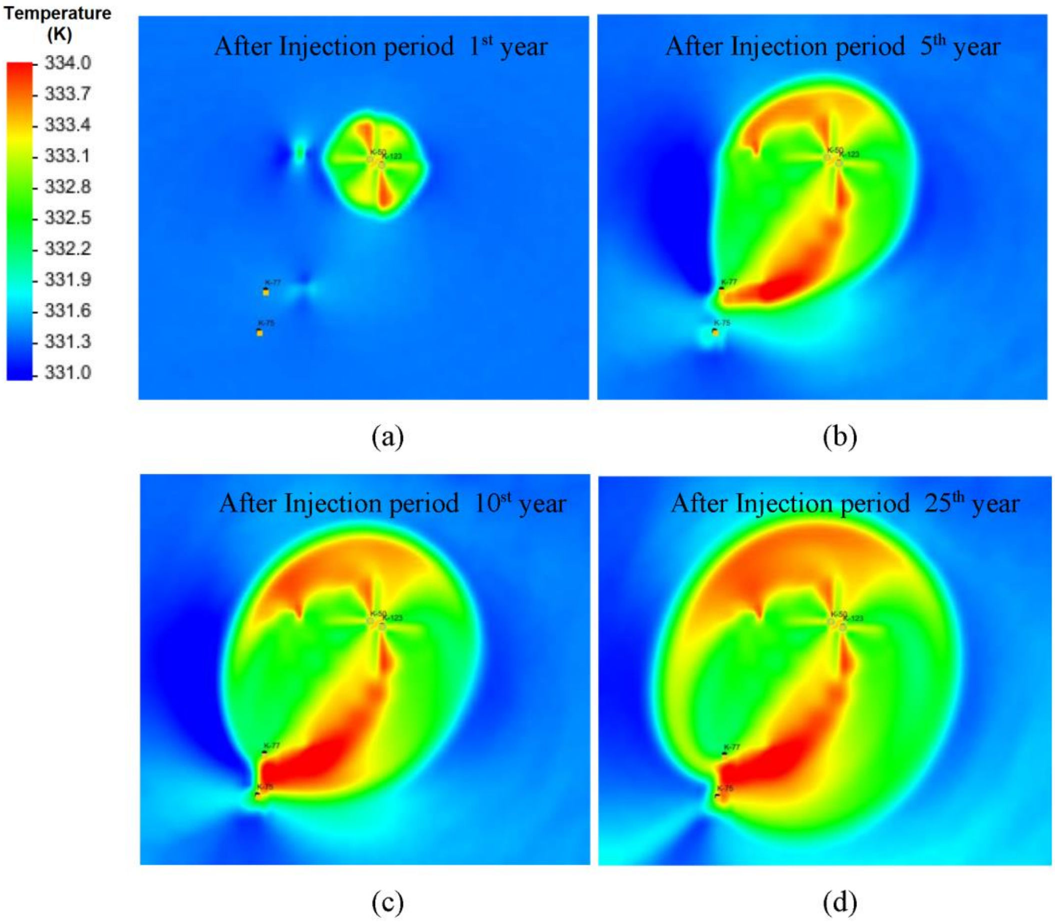

Figure 7. *For the second scenario, temperature distributions are shown at different times during injection a) the first year b) the fifth year c) the tenth year and d) the last day of the twenty-fifth year*

References

[1] Lee, K. S. (2013). *Underground thermal energy storage: Green energy and technology series*. Springer-Verlag London. ISBN: 978-1-4471-4272-0, pp. 1-151.

[2] Nielsen, K. (2003). Thermal energy storage A State-of-the-Art. *NTNU*, 4-15.

[3] Miklós, R.: *Potenciális termálkarsztvíz áramlási pályák lehatárolási lehetősége a Bükk dél-keleti előterében*, 2018 14th International Scientific Conference on Mineral Waters of the Carpathian Basin, Košice, Technical University of Kosice, 122 p., pp. 46-56., 11 p.

[4] Dinc, I., Rosen, M. A. (2011). *Thermal energy storage - Systems and Applications*. Second Edition, John Wiley and Sons, Ltd. ISBN: 978-0-470-97073-7, pp. 51-186.

[5] Bridger, D. W., Allen, D. M. (2010). *Heat transport simulations in a heterogeneous aquifer used for aquifer thermal energy storage (ATES)*. Can. Geotech. J. 47, 96–115. **https://doi.org/10.1139/T09-078**

[6] Hecht-Méndez, J., Molina-Giraldo, N., Blum, P. & Bayer, P. (2010). Evaluating MT3DMS for heat transport simulation of closed geothermal systems. *Groundwater*, 48, 741-756. **https://doi.org/10.1111/j.1745-6584.2010.00678.x**