Numerical simulation of a heat exchanger using $\text{Al}_2\text{O}_3$ nanofluid and STES

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Abstract. The major energy crisis, predictable for the global economy, requires attentive research & development in order to grow energy performance, heat transfer and energy storage. It is a known fact that in the energy balance, the biggest share is in thermal energy and that justifies the continuous effort in the optimization of fossil fuel saving solutions and intense promotion of renewable energies. Use of the latter in heating and cooling systems as well as “waste heat” from different processes is consistent with the concept of sustainable development and results in reduction of conventional fuel consumption and emissions. Optimizing such a system can be made by replacing the usual storage material with phase changing materials and by using nanofluids as a secondary agent with the beneficial effect on heat transfer. In this paper we have studied a simplified multitubular heat exchanger, buried in the ground, having as a primary working fluid plain water and nanofluid, using Ansys. The nanofluid is composed of particles of $\text{Al}_2\text{O}_3$ dispersed in water at a concentration of 1%. The study indicates an increase in convective heat transfer coefficient of nanofluid compared to water.

1. Introduction
The national energy strategy, correlated with the EU directives, provides for important measures to improve the energy efficiency of buildings and related facilities, as well as for the use of advanced technologies by promoting appropriate solutions and equipment in full knowledge of the peculiarities and applicability limits to solve different categories of requirements with maximum functional and energy efficiency. [1]

The use of heating and cooling systems for the use of renewable forms of heat and heat from different processes is consistent with the concept of 'sustainable development' and directly contributes to reducing conventional fuel consumption and emissions.

The summer heat surplus can be accumulated in the seasonal storage, which replaces natural sources, ensuring the functional conditions and autonomy of systems.

Granular materials, phase or water change materials, well-sized and customized design conditions can be used as storage media. The solution is reasonable for systems with small and medium capacities applied to objectives located in isolated locations. [2]

Research programs have been supported within the Department of Building Services Engineering at the Technical University of Iasi and have the main objective to increase the overall efficiency of plant systems. The themes of two doctoral theses were preserved in the complex study of thermal storage (cold sources), with seasonal self-compensation and also one regarding the usage of nanofluids in thermal processes.

In the paper we have analysed the possibilities of functional and energetic optimization of the local systems of systems using nanofluid as a primary working fluid in heat exchangers embedded in storages with controlled thermophysical characteristics and with cyclic operation.
2. System description

2.1. Seasonal thermal energy storage
Thermal energy storage allows thermal energy to be collected for later use (hours, days or even months). It is a valuable asset and can be applied for individual buildings that are isolated and also for larger buildings such as schools, hospitals and even for an entire town. So, energy demand can be balanced between day and night or winter and summer. Geothermal heat pumps and nanofluids are the influencing factors to improve the system performance.

In the case of surface or deep geothermal sources, the quantities of heat absorbed under natural conditions are conditioned by the thermophysical characteristics of the soil and by the evolution of the ambient temperature influenced by the seasonal variation of the climatic factors.

Since the cooling load is higher than the heating load, for systems equipped with reversible heat pumps, the storage size must be adjusted according to the heating mode.

From a constructive point of view, the solution can be embodied in small or medium depths, preferably in the form of underground enclosures, wells or large diameter wells and depths up to 10 m, individual or parallel coupled, depending on the storage volume necessary.

2.2. Nanofluid
There are fluids that contain particles of nanometric size (1 \times 10^{-9} \text{ m}), called nanoparticles usually made of metals, oxides, carbon or carbon nanotubes. Common base fluids include water, ethylene glycol and oil.

The first studies on nanofluid behaviour and their performance were made in the Argon National Laboratory by Choi between 1995 and 1999.

The research that has taken place over the years has been aimed at determining the thermal conductivity of nanofluids with different volumetric concentrations (0.5-4%), but also different basic fluids. Between these volumetric concentrations, increases in thermal conductivity of about 25% compared to those of the base fluids used were observed. [3]

Results have shown that nanofluids have distinctive features such as: an improvement in convective transfer coefficient in the case of low particle concentration, an increase thermal conductivity and also in flow heat.

Experiments made by Wen&Ding, in laminar regime, using nanofluid composed of water and Al_{2}O_{3} and a copper tube have revealed that an increased volume concentration of particles also increases thermal transfer, Reynolds number by 40% and thermal conductivity by 15%.

In the case of turbulent regime, Reynolds number is less influenced compared to laminar regime but there has been an increased thermal transfer as well.

So it is safe to say that by using nanofluids, we are able to obtain low-temperature heat transfer systems with low production costs but with increased energy efficiency, thanks to the physical-mechanical characteristics that they present: low pulse, increased mobility and high surface/volume ratio.

3. Numerical modelling

3.1. Geometry
Using Autodesk Inventor we were able to define a cube of quart sand with the following dimensions: L x L x H = 1x1x1 \text{ m} and a copper tube of 1 m in length with a diameter of 1”.

The next step was to insert the copper tubes in the quartz sand cube, at equal distances.

The objective here is to compute heat transfer per tube row to the storage. So it is a physical system in which we have a complicated setup of several cascade of tubes. To start with and due to the fact that
the length for a paper is limited, we proceeded to solve this case by simplifying it - taking a section for analysis and set-up the working conditions. More results have been obtained after, which are available upon request.

![Figure 1. Quartz sand cube](image1.png)  ![Figure 2. Copper tube](image2.png)

3.2. *Ansys Fluent*

Simulations of working conditions were done using the Ansys Fluent program. It uses CFD methodology, a science that predicts fluid flow, heat and mass transfer, chemical reactions and the resulting phenomena.

Thus CFD process in overall is a 3 step procedure:

**Pre-processing:** This step consisted in defining a geometry to our domain of interest. The domain of interest is then divided into segments, called as mesh generation step and the problem is set-up defining the boundary conditions.

**Solver:** Once the problem is set-up defining the boundary conditions we have solved it with the software on the computer. The numerical methods are also defined at this stage and we solve the whole problem.

**Post-processing:** Once we get the results as values at our probe points we have analysed them by means of colour plots, contour plots and appropriate graphical representations.

![Figure 3. Copper tubes inserted in the quartz sand cube.](image3.png)
3.3. Working hypotheses

- Nanofluid working temperatures: 50, 60, 70, 80 90°C;
- Flows: 0.5, 0.6, 0.7, 0.8, 0.9 m³/h;
- Nanoparticle concentrations: 0% (water), 1%.

Water properties:
- ρ = 1000 kg/mc
- Cp = 4500 J/kg*K
- Λ = 0.9 W/m*K
- µ = 0.0015 kg/m*s

Quartz sand properties:
- ρ = 1600 kg/mc
- Cp = 795 J/kg*K
- Λ = 0.2 W/m*K

Also, the assumptions are:
- flow is laminar and translationally periodic (i.e. geometry repeats itself)
- flow approaching tube bank is steady with a known velocity
- body forces due to gravity are negligible

Table 1. Water properties with 1% nanofluid concentration.

| Temp [°C] | ρ [kg/mc] | Cp [J/kg*K] | µ [kg/m*s] | Λ [W/m*K] |
|-----------|------------|-------------|------------|-----------|
| 50        | 1036.5     | 4147.0      | 0.00059    | 0.66037   |
| 60        | 1032.0     | 4159.5      | 0.00050    | 0.67103   |
| 70        | 1027.0     | 4172.8      | 0.00043    | 0.68025   |
| 80        | 1021.2     | 4187.1      | 0.00038    | 0.68804   |
| 90        | 1014.8     | 4202.4      | 0.00034    | 0.69445   |

4. Results

The temperatures along the copper tube are shown in the images bellow, for different inherent temperatures and flows, for water (fig. 4,6, 8, 10, 12) and water with 1% nanofluid (fig. 5, 7, 9, 11, 13)

Figure 4. 50°C, 0.5 m³/h (water)

Figure 5. 50°C, 0.5 m³/h (1% nano)
Figure 6. 60°C, 0.6 m³/h (water)

Figure 7. 60°C, 0.6 m³/h (1% nano)

Figure 8. 70°C, 0.7 m³/h (water)

Figure 9. 70°C, 0.7 m³/h (1% nano)

Figure 10. 80°C, 0.8 m³/h (water)

Figure 11. 80°C, 0.8 m³/h (1% nano)
Figure 12. 90°C, 0.9 m³/h (water)

Figure 13. 90°C, 0.9 m³/h (1% nano)

Figure 14. Temperature contours around tubes

5. Conclusions
As seen, the regions near the tube wall have re-circulation zones as a result of which there is a heat built-up (red colour) also shown by colour variations. So we see that we can have a very nice depiction of real life situation through a simple 2-D analysis.
From the experimental system, the values that have been measured are, the temperatures of the inlet and outlet of the hot water as well as the inlet of the distilled water and the different concentrations of nanofluids at different mass flow rates.

The conclusions of the numerical study have highlighted the intensification of heat transfer, when using nanofluids, compared to water. [4][5]

6. References

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