 

# THERMAL CONVECTION ANALYSIS OF HEAT PUMP SYSTEMS

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**Abstract.** Correlated with EU directives, the national energy strategy provides important measures in order to improve energy efficiency in buildings and related facilities, as well as using advanced technologies and materias and by promoting appropriate solutions and equipment in full knowledge of the peculiarities and applicability limits for different categories of requirements, with maximum functional and energy efficiency. Since it is known that in the energy balance the biggest share is in thermal energy, it is appropriate to say that continuous efforts in the optimization of conventional fuel saving solutions and intense promotion of renewable energies is highly justified. Also taking into account the major energy crisis, foreseeable for the global economy, we can say that there is a need for a series of research and development strategies in terms of energy performance, transport and storage. The use of renewable energy forms in the cooling and heating systems, as well as the „waste heat" resulted from different processes is consistent with sustainable development and helps reduce the consumption and emissions of conventional fuels. Plant systems equipped with heat pumps with mechanical vapor compression require the existence of an additional source with a low thermal potential, normally obtained from the natural environment. For example, the additional source can be arranged in line with the utilization of the residual heat from the system in self-compensating regime, when the system is designed to heat the space during the cold season and cool it during summer. In this case, the heat surplus from the cooling operation is gathered in seasonal storage and provides the necessary intake for heating, resulting the autonomy and independence of the system regardless the natural thermal resources. Replacing the usual secondary agent with nanofluids increases heat transfer by significantly increasing the convective transfer coefficient and also the storage of thermal energy in phase-change materials is a method that has experienced significant development in recent years, being attractive in terms of the large amount of thermal energy accumulated by the storage medium per unit volume at constant temperature.

## 1 Introduction

The major energy crisis, predictable for the global economy, requires R & D strategies to focus primarily on increasing the energy performance of power generation, transmission, transport and storage equipment.
In this respect, one of the major challenges for the European Union is how to ensure the energy security of Member States, taking into account the evolution of climate change and the uncertain future of access to energy resources.
It is a known fact that the highest share, in the energy balance, is represented by thermal energy and so the continuous effort in order to optimize saving solutions for fossil fuels and promotion of renewable energies is well justified.
The use of plant systems for the use of renewable forms of energy as well as waste heat from different processes corresponds to the concept of "sustainable development" and directly contributes to reducing conventional fuel consumption and emissions. [1]
In the category of unconventional forms, shallow geothermal energy - recovered through heat pumps - is a source with great potential for saving primary resources and achieving the goals set for the 2030 and 2050 stages.
**Seasonal Thermal Energy Storage (STES)** is generically used and refers to technologies for storing "heat" or "cold" for a period of time that may be up to a several months. Available thermal energy can be collected, stored and used when necessary, such as in opposite seasons. For example, residual heat, waste heat from industrial processes or the heat from solar panels can be collected during the summer and used, in a system equipped with a heat pump, to ensure the comfort parameters during winter. The same principle is applied when collecting natural cold, used during the hot season for cooling. [2]

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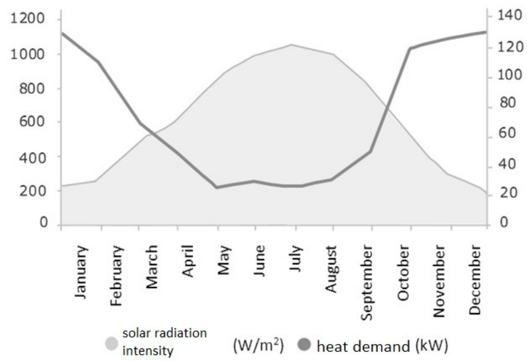


**Fig. 1.** Solar radiation/heat demand during the year.

In the case of air conditioning units designed for cooling in the warm season and for cold season heating, there is a need for an additional source, which can be appropriately arranged for the recovery of the residual heat energy from the system in a self-extinguishing regime. This creates autonomy of the system independent of natural thermal resources.

Achieving an efficient heat transfer between the working environments of geothermal exchangers is conditional on their thermophysical parameters and the improvement of the overall transfer coefficient through constructive performance solutions.

Also, increasing the heat storage capacity by using controlled materials ensures the efficiency of the system.

# 2 Components

## 2.1. Heat exchangers

Heat capture in the soil can be achieved through heat exchangers also known as collectors. They consist of tubes in closed loops through which circulates the working fluid (water, various glycol solutions, nanofluid etc.) and, properly dimensioned, can recover the stored energy soil at a temperature compatible with a suitable heating system (low temperature radiation – floor, radiant walls or ceilings).

Considering that the system chosen for the numerical simulation presented in the paper is **Borehole Thermal Energy Storage (BTES)**, it is made clear that in the volume of earth will be introduced more vertical tubes at equal distances between them. Among the advantages of this solution we mention the fact that the soil is a very good medium for storage of thermal energy because it does not involve costs (it is already in the place where we want to implement the system), it is not harmful to the environment or people and above these drillings can parking facilities, playgrounds, green spaces etc. The volume of water flowing through the heat exchanger is used to load or discharge the system at different time intervals. [2]

## 2.2 Nanofluids

Nanofluid research began in the 1980s, but the nanofluid concept only appeared in 1995 at the Argon National Laboratory in Chicago by Choi. It described a new fluid in which nanomaterial particle suspensions (<100 nm) are present.

The benefit of using nanofluids is that we can obtain low-temperature heat transfer systems with low production costs but with increased energy efficiency. This is due to the physic-mechanical characteristics that nanoparticles have: high surface / volume ratio, low pulse, increased mobility. [4]

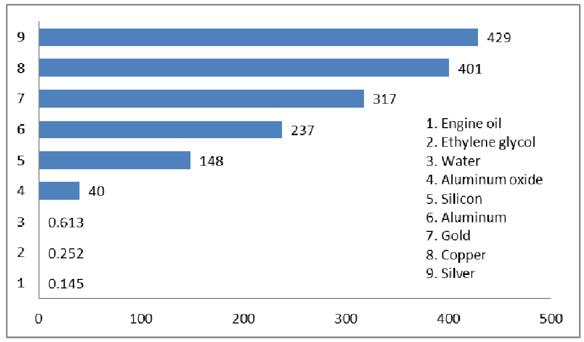


**Fig. 2.** Thermal conductivity of solid and liquid materials at 300 K

# 3 Numerical simulation

## 3.1. Description of geometry

The geometry for the numerical simulation was developed with the help of Autodesk Inventor. The dimensions adopted for the quartz sand "cube" were Lxlxh = 1x1x1 m. The length of the tube used is 1 m and the diameter is 1 ". [2]

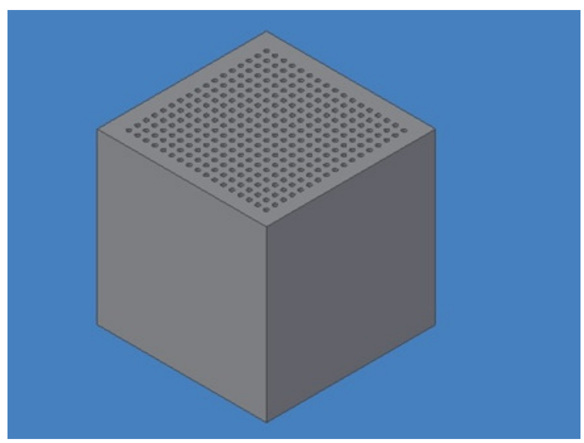

**Fig. 3.** Quartz sand “cube” (1x1x1 m)

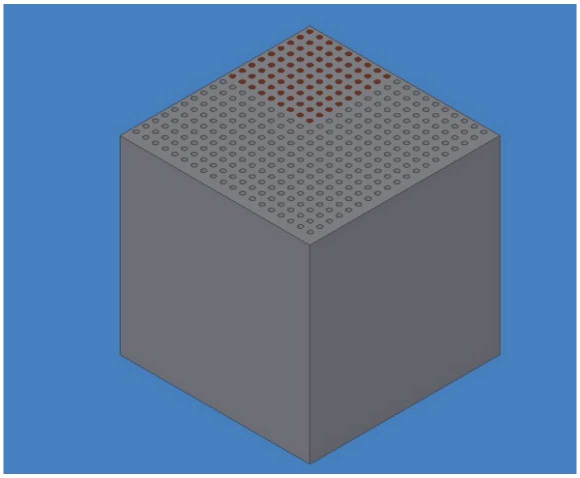

**Fig. 4.** Inserted copper tubes at equal distances

In order to simplify and reduce the time of simulations, the geometry was reduced to only one tube, as presented in the image below. Further, with the help of similarities, the results obtained for the other tubes can be applied.

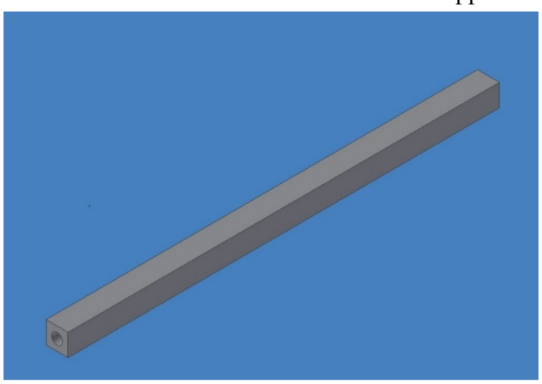

**Fig. 5.** Simplified case

### 3.2. Working hypotheses

Simulations of working conditions were done using the **Ansys Fluent** program. [2]

• Nanofluid working temperatures: 50, 60, 70, 80 90℃;
• Flows: 0.5, 0.6, 0.7, 0.8, 0.9 mc / h;
• Nanoparticle concentrations: 0%, 1%, 2%, 3%, 4%.

Water properties:
• ρ = 1000 kg/m$^3$
• Cp = 4500 J/kg*K
• Λ = 0.9 W/m*K
• μ = 0.0015 kg/m*s

Quartz sand properties:
• ρ = 1600 kg/m$^3$
• Cp = 795 J/kg*K
• Λ = 0.2 W/m*K

**Table 1.** Water properties with 1% nanofluid concentration.

| Temp. [℃] | 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 |

**Table 2.** Water properties with 2% nanofluid concentration.

| Temp. [℃] | ρ [kg/mc] | Cp [J/kg*K] | μ [kg/m*s] | Λ [W/m*K] |
|---|---|---|---|---|
| 50 | 1085.2 | 4113.0 | 0.00065 | 0.67917 |
| 60 | 1080.7 | 4125.3 | 0.00055 | 0.69011 |
| 70 | 1075.5 | 4138.5 | 0.00048 | 0.69958 |
| 80 | 1069.7 | 4152.6 | 0.00042 | 0.70758 |
| 90 | 1063.3 | 4167.7 | 0.00037 | 0.71416 |

**Table 3.** Water properties with 3% nanofluid concentration.

| Temp. [℃] | ρ [kg/mc] | Cp [J/kg*K] | μ [kg/m*s] | Λ [W/m*K] |
|---|---|---|---|---|
| 50 | 1133.9 | 4078.9 | 0.00072 | 0.69833 |
| 60 | 1129.3 | 4091.1 | 0.00062 | 0.70957 |
| 70 | 1124.1 | 4104.2 | 0.00053 | 0.71928 |
| 80 | 1118.3 | 4118.1 | 0.00047 | 0.72750 |
| 90 | 1111.8 | 4133.1 | 0.00041 | 0.73425 |

**Table 4.** Water properties with 4% nanofluid concentration.

| Temp. [℃] | ρ [kg/mc] | Cp [J/kg*K] | μ [kg/m*s] | Λ [W/m*K] |
|---|---|---|---|---|
| 50 | 1182.5 | 4044.8 | 0.00081 | 0.71787 |
| 60 | 1177.9 | 4056.9 | 0.00069 | 0.72940 |
| 70 | 1172.7 | 4069.8 | 0.00060 | 0.73938 |
| 80 | 1166.8 | 4083.6 | 0.00052 | 0.74781 |
| 90 | 1160.2 | 4098.4 | 0.00046 | 0.75474 |

## 4 Results

To evaluate the accuracy of measurements, experimental system has been tested with distilled water before measuring the heat transfer characteristics of different volume concentration of $Al_2O_3$/water.
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 numerical model, performed by the FLUENT calculation program, allowed the qualitative and quantitative analysis of the influence of the volume concentration of the solid phase on the temperature and velocity spectra, respectively on the main parameters involved in the thermal transfer, namely the convective

transfer coefficient, the global coefficient of thermal transfer and thermal efficiency.

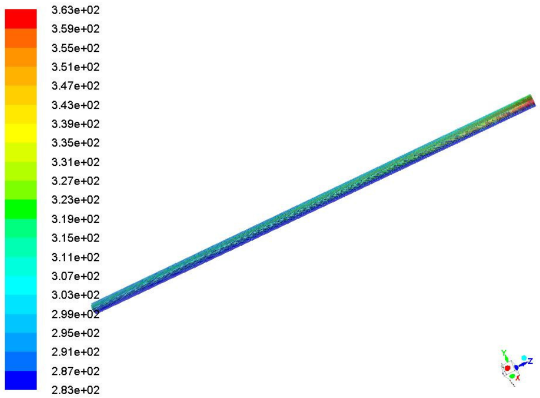


**Fig. 7.** 0% nano, 90℃, 0,9 $m^3$/h

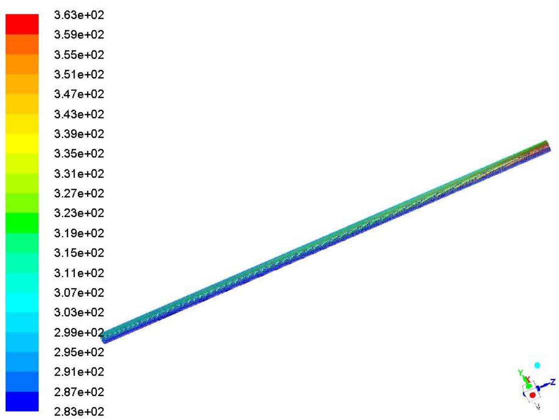


**Fig. 8.** 1% nano, 90℃, 0,9 $m^3$/h

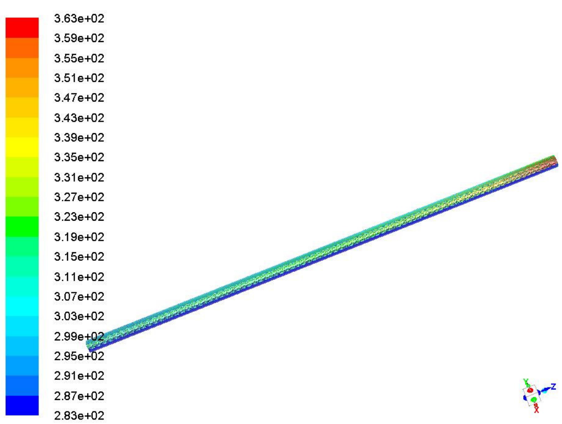


**Fig. 9.** 2% nano, 90℃, 0,9 $m^3$/h

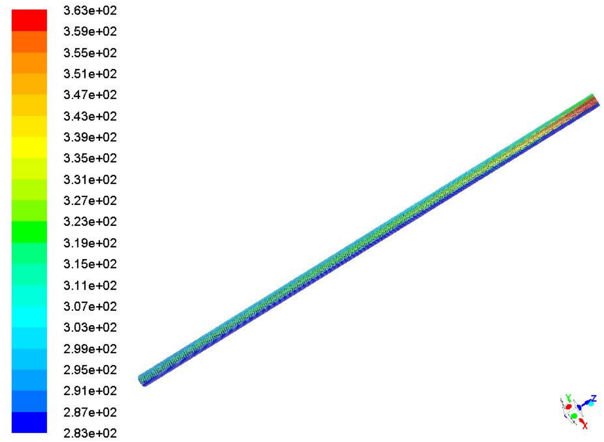


**Fig. 10.** 3% nano, 90℃, 0,9 $m^3$/h

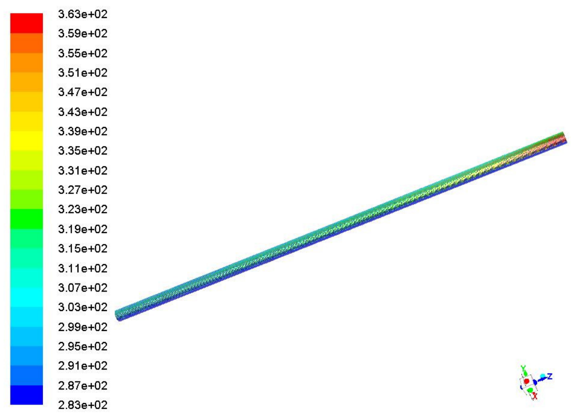


**Fig. 11.** 4% nano, 90℃, 0,9 $m^3$/h

The conclusions of the numerical study have highlighted the intensification of heat transfer, when using nanofluids, compared to water. Thus, we can say that of the 4 concentrations proposed in the working hypotheses, the best results we have for the 2% concentration. [5]

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