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Analysis of the thermo-convection variation in tubular heat exchangers functioning with nanofluid

Andreea-Irina Baran[2], Theodor Mateescu[1]
[1]Ph.D. Student, Department of Building Services Engineering, "Gheorghe Asachi" Technical University of Iasi
[2]Ph.D. Supervisor, Department of Building Services Engineering, "Gheorghe Asachi" Technical University of Iasi

Summary

The paper presents the results of the numerical research carried out on a thermal storage module equipped with fascicle geoschimbers, working with nanofluid. The original design solution is designed for seasonal heat storage in heating / air conditioning systems for buildings and shows interest in superior energy efficiency compared to classical solutions. The study is carried out with the purpose of capitalizing the results for the realization of variable geometry modular geothermal heat exchangers. The advantage of the modular concept consists in increasing the energy efficiency and uniformity of the heat flow, ie the demand of the storage mass, by the dimensioning of the heat transfer surface inversely proportional to the temperature difference between the fluid and the solid. The use of nanofluids as a calizo agent is justified by the superior thermophysical performance of water, used in classical solutions.

Keywords:

1. INTRODUCTION

Seasonal Thermal Energy Storage (STES) is a concept that refers to various technologies for storing heat or "cold" for periods of up to several months for reuse during periods of dearth. Excessive heat may be collected when available and used to offset the requirement as required. For example, thermal energy from solar panels or residual heat from air conditioning equipment can be collected in the summer months and used to heat the space during the winter months. The natural cold in winter outdoor air can also be stored and used in summer in conditioning.

Several STES heat storage solutions are known to cover a wide range of applications ranging from small, isolated buildings to urban networks. In general, energy efficiency increases and specific construction costs decrease with size. UTES (underground thermal energy storage - underground thermal energy storage in the soil can be done in the following variants:

- **ATES** (aquifer thermal energy storage) - storage of thermal energy in the aquifer

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- **Borehole thermal energy storage** (BTES) - thermal storage in the ground using deep drilling
- **CTES** (cavern or mine thermal energy storage) - storage of thermal energy in caverns or underground galleries
- **Storage in mixed-function pilots** - resistance and energy

In all these solutions, the heat exchangers with the soil are of the linear type - closed loops - of constant geometry, using water as the agent or glycolic solution. As the main disadvantage, the heat flow is uneven across the exchanger.

In the envisaged solution, by realizing the apparatus from the insured modules having transfer surfaces dimensioned in a ratio inversely proportional to the temperature difference between the thermal agent and the soil, the heat flow and the stator load are uniformized.

Nanofluids are colloidal nanoparticle suspensions (1x10-7 - 1 × 10-9 m) in a base fluid. Nanoparticles used are usually made of metals, oxides, carbides or carbon nanotubes. Common base fluids include water, ethylene glycol and oil.

2. NUMERICAL RESEARCH

Due to the specific properties, the thermal conductivity increases and the convective heat transfer coefficient is comparable to the basic fluid.

2.1 Working hypoteses

In the case of the study it was considered a storage module with dimensions 1.0x1.0x1.0 m made of quartz sand with constant granulometric and thermophysical characteristics, in which are implanted copper pipe sections with diameter 1 "and length of 1.0 m, disposed at different distances: 1d, 1.5d, 2d.

Working fluid was considered comparatively water and a nanofluid composed of Al2O3 particulate water at concentrations of 2% and 4%. Working temperatures were considered to be 50, 70 and 90°C, and flow rates of 0.5, 0.7 and 0.9 m3 / h.

Output parameters were evaluated for convective transfer coefficients, working agent temperatures at exchanger exit and flue gas spectra across the exchanger.

2.2. Mathematical model

Modeling was performed in the ANSYS program using the CFD approach that uses a numerical equation solving technique that governs flow in different types of geometry, depending on the boundary conditions. It presents the advantage that it reduces the number of experiments required and gives results that would be difficult to determine experimentally.

The temperature and flow fields for single-phase fluids in a tubular element are determined by solving the following equations:

Continuity equation:

$$\frac{\partial \mathrm{p}}{\partial \mathrm{t}} + \nabla(\rho \mathrm{U}) = 0 \tag{1}$$

Equation of preservation of the amount of motion:

$$\frac{\partial}{\partial t}(\rho U) + \nabla(\rho U U) = -\nabla P + \nabla \tau + B \tag{2}$$

Equation of energy conservation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla(\rho U C p T) = \nabla(k \nabla T) \tag{3}$$

In order to solve the stated equations we have calculated the thermo-physical parameters of the nanofluids used using the known relations:

Density:

$$\rho_{\mathrm{nf}} = (1-\phi)\rho_{\mathrm{f}} + \phi\, \rho_{\mathrm{p}} \tag{4}$$

Specific heat:

$$\mathrm{C}_p = (1-\phi)\mathrm{C}_{\mathrm{pf}} + \phi\, \mathrm{C}_{\mathrm{pp}} \tag{5}$$

Viscosity:

$$\mu_{nf} = (1 + 2.5\phi)\mu_{\mathrm{f}} \tag{6}$$

Thermal conductivity:

$$\lambda_{\mathrm{nf}} = \frac{\lambda p + 2\lambda f + 2(\lambda p - \lambda f)\phi}{\lambda p + 2\lambda f - (\lambda p - \lambda f)\phi}\lambda_{\mathrm{f}} \tag{7}$$

Relationships where:

Φ [%] - volume concentration of the solid particle

ρp, f [kg / m3] - particle / fluid density

Cpp, f [J / kg * K] - specific heat of the particles / fluid

λp, f [W / mK] - thermal conductivity of the particles / fluid

The results are presented numerically in the table below:

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Table 1. *Numerical results – water and water + nanofluid*

Concentration	**Temperature**	**ρ**	**Cp**	**μ**	**Λ**
%	*grd C*	*kg/mc*	*J/kg*K*	*kg/m*s*	*W/m*K*
0	50	1000	4500	0.0015	0.9
	70				
	90				
2	50	1085.2	4113	0.00065	0.67917
	70	1075.5	4138.5	0.00048	0.69958
	90	1063.3	4167.7	0.00037	0.71416
4	50	1182.5	4044.8	0.00081	0.71787
	70	1172.7	4069.8	0.0006	0.73938
	90	1160.2	4098.4	0.00046	0.75474

2.3. Models geometry

The geometry of the studied model was developed using Autodesk Inventor 2016. The dimensions adopted for the quartz sand module were L x l x h = 1.0x1.0x1.0 m (Figure 1) and the used tubular element is 1 m long and 1 " (Figure 2).

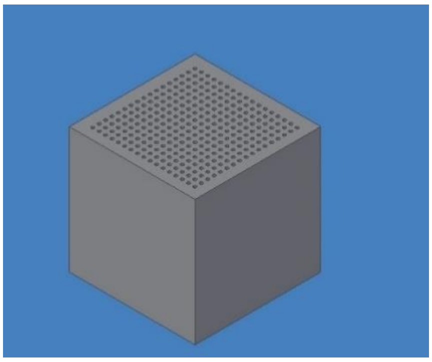

Fig. 1: Quartz sand cube

Fig. 2: The copper tube

2.4. Results

In order to compare the three types of fluids: water and two suspensions with different concentrations of nanofluid, numerical simulations were performed to establish the correlations between the Reynolds flow regimes and the convective transfer coefficient α.

The Reynolds number is defined by the relationship:

$$\mathrm{Re}_{nf} = \frac{u_m L}{\nu_{nf}} \quad (8)$$

The value of the convective coefficient α is calculated using the Nusselt number:

$$Nu = (\alpha * L)/\lambda \quad (9)$$

The convective coefficient is calculated with the relation:

$$\alpha = (Nu * \lambda)/L \quad (10)$$

The temperature and speed spectra describing the evolution of the transfer phenomena are viewed after the completion of the calculation process.

Figure 3 illustrates an example of temperature visualization in one of the cases studied. The color legend highlights temperature variation from 323 to 310.83 K, depending on the required boundary conditions.

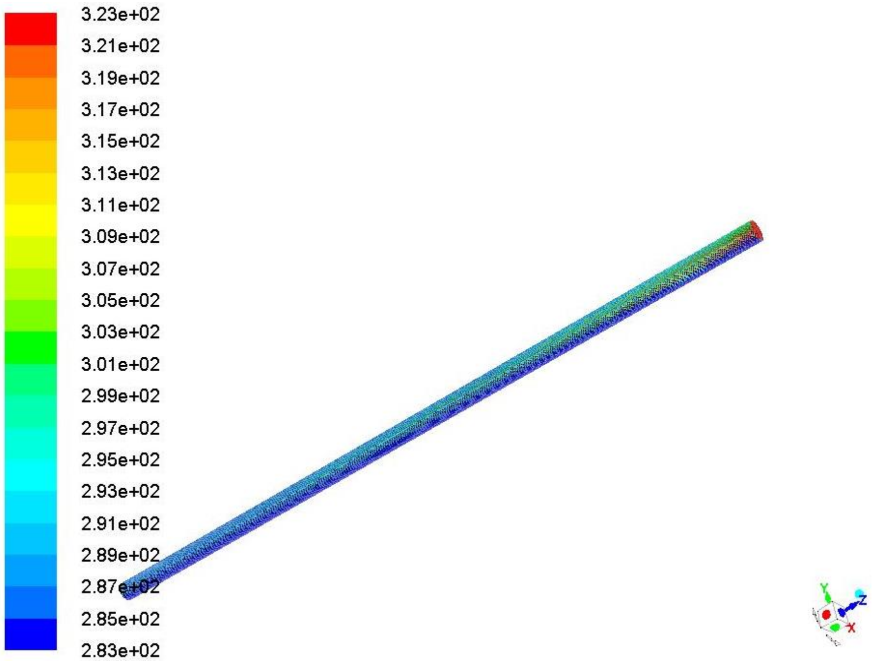

Figure 3. Temperature profile for Al_2O_3- 2%

In Figures 4 and 5, the values of the convective transfer coefficient and of the exit temperatures corresponding to the different thermo-hydraulic regimes are represented.

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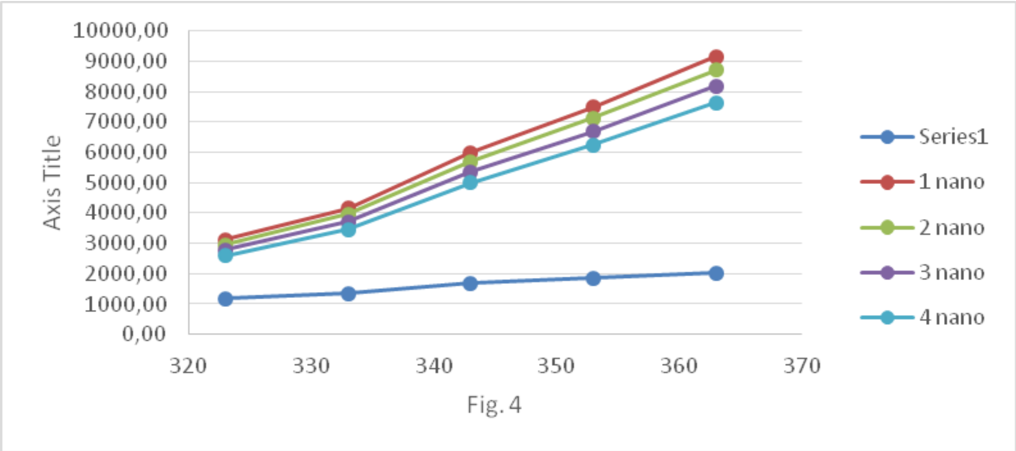

Figure 4.

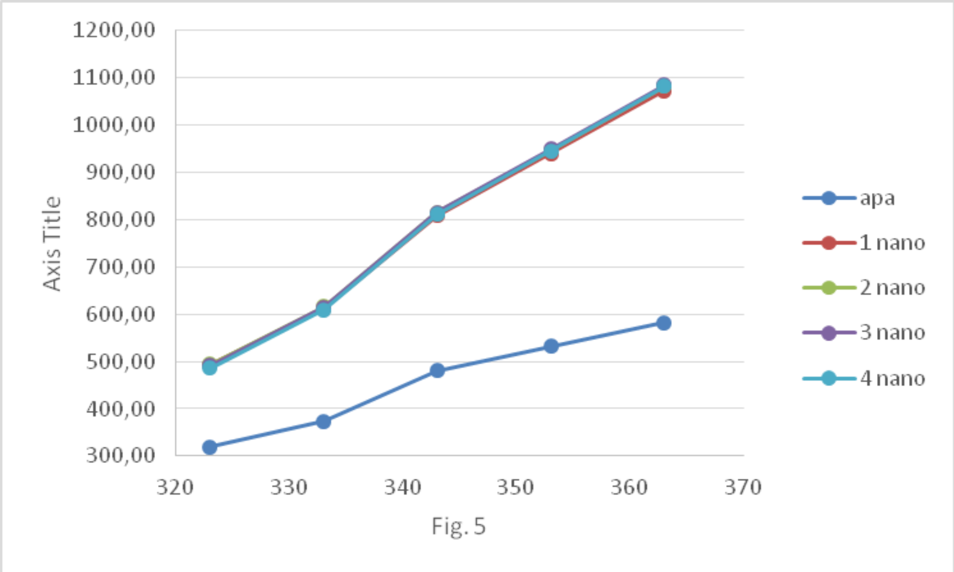

Figure 5.

3. CONCLUSIONS

In the paper, the thermal transfer capacity of a caliber agent consisting of water with different concentrations of nanofluid to the transfer surfaces of the tubular modules was studied comparatively.

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The results confirm the superior efficacy of the nanofluid constituted by suspensions of metallic materials in water, directly proportional to the solids concentration.

Under the conditions of the adapted working hypotheses, the optimal solution corresponds to the 2% concentration.

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