11. Кузнецов Г. В., Орлова Е.Г., Феоктистов Д.В. Режимы растекания капли воды по подложкам с различной смачиваемостью // Инженерно-физический журнал. - 2016. - Т.89. - N 2. - С. 310-315.
12. Bo Wu, Ming Zhou, Jian Li, Xia Ye, Gang Li, LanCaiSuperhydrophobic surfaces fabricated by microstructuring of stainless steel using a femtosecond laser // Applied Surface Science. - 2009. - Т. 256. - С. 61–66.
13. Cardoso M.R., Tribuzi V., Balogh D.T., Misoguti L., Mendonce C.R. Laser microstructuring for fabricating superhydrophobic polymeric surfaces // Applied Surface Science. - 2011. - Т. 257. - С. 3281–3284.

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NATURAL CONVECTION OF NANOFLUID FROM AN ISOTHERMAL VERTICAL FLAT PLATE USING SINGLE-PHASE MODEL

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Abstract: Free convection from an isothermal vertical wall embedded in a water-based nanofluid is studied numerically using boundary layer approach and similarity method. The obtained results allow to analyze the effects of nanoparticles volume fraction and type of nanoparticles material on nanofluid flow and heat transfer.

1. Introduction

Obviously, low thermal conductivity coefficient of traditional coolants is the main problem that prevents to an intensification of heat transfer in energy systems. It has been shown experimentally [1, 2], that one of interesting and effective technique for the heat transfer enhancement is to add metallic nanoparticles or their oxides inside the conventional fluids. The obtained fluid known as nanofluid is the suspension of clear fluid and metallic nanoparticles or their oxides. A large number of conflicting experimental data does not allow to clearly explain the reasons for a significant change in transport regimes of mass, momentum and energy in nanofluids. Therefore, the most effective method for the study of hydrodynamics and heat transfer in these environments is to solve the equations of mathematical physics, developed on the basis of the conservation laws of continua mechanics.

2. Mathematical model

In the present work we numerically analyzed free convection of nanofluid from the vertical isothermal flat plate presented in Fig. 1.

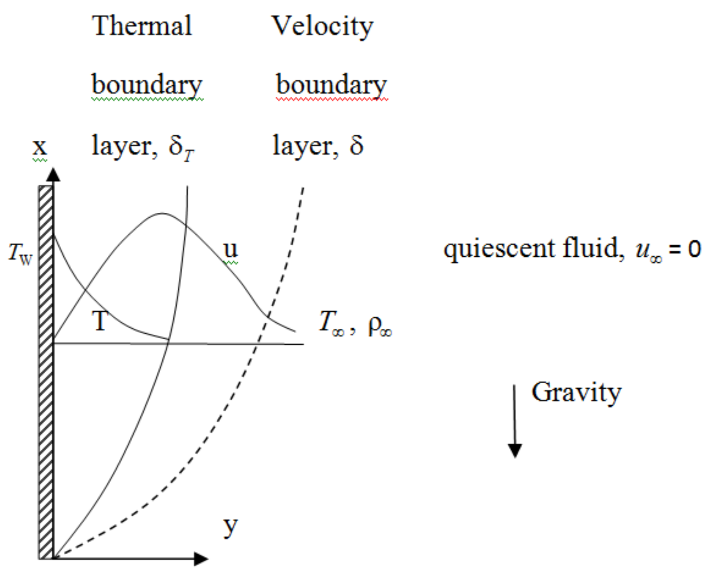

Fig. 1. Physical model.

For mathematical analysis the authors have utilized partial differential equations on the basis of the boundary layer approach [2, 3]. These equations have been formulated taking into account the conservation laws for mass, momentum and energy:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{1}{\rho_{nf}}\left[\mu_{nf}\frac{\partial^2 u}{\partial y^2}+(\rho\beta)_{nf}\,g(T-T_\infty)\right] \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{1}{(\rho C_p)_{nf}}k_{nf}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

The following boundary conditions have been added to the formulated governing equations (1)–(3):

$u = v = 0$, $T = T_w$ at vertical wall $y = 0$

$u \to 0$ and $T \to T_\infty$ at $y \to \infty$

where T_w is the temperature of vertical wall and T_∞ is the temperature of ambient fluid.

For solution to the formulated boundary-value problem the author has used the similarity method with following non-dimensional variables [4]:

$$\eta=\frac{y}{x}\left(\frac{Gr_x}{4}\right)^{1/4},\quad \psi=4\nu f(\eta)\left(\frac{Gr_x}{4}\right)^{1/4},\quad \theta=\frac{T-T_\infty}{T_w-T_\infty}$$

Taking into account these dimensionless variables governing equations can be written as a system of two ordinary differential equations:

$$\begin{cases}\dfrac{\mu_{nf}}{\rho_{nf}}\dfrac{\rho_f}{\mu_f}f'''+3ff''-2(f')^2+\dfrac{(\rho\beta)_{nf}}{\rho_{nf}\beta_f}\theta=0\\[2ex] 3f\theta'+\dfrac{k_{nf}}{Cp_{nf}\mu_{nf}}\theta''=0\end{cases}$$

The effective dynamic viscosity and thermal conductivity of nanofluid have been defined on the basis of the Brinkman's law [5] and Maxwell's model [6], respectively. Brinkman's law for the viscosity of nanofluid is $\mu_{nf} = \frac{\mu_f}{(1-C_v)^{2.5}}$, where C_v is the nanoparticles volume fraction. Maxwell's model for thermal conductivity of nanofluid is $k_{nf} = k_f \left(1 + \frac{3C_v(\frac{k_p}{k_f} - 1)}{\frac{k_p}{k_f} + 2 - C_v(\frac{k_p}{k_f} - 1)} \right)$, where k_p, k_f, k_{nf} are the thermal conductivity of nanoparticles, base fluid and nanofluid.

The formulated ordinary differential equations with appropriate boundary conditions have been solved by Runge–Kutta method combined with shooting technique.

3. Results and discussion

The effects of nanoparticles volume fraction in the range 0–4% and types of nanoparticles material (Ag, Cu, Al_2O_3, CuO, TiO_2) have been analyzed. A comparison between clear fluid and a nanofluid containing Cu nanoparticles with concentration of 4% is also carried out.

Profiles of dimensionless velocity and temperature at C_v=0.04 are presented in Figs. 2 and 3 in comparison with clear fluid. An addition of nanoparticles inside the clear fluid leads to the velocity reduction due to a growth of the dynamic viscosity, while temperature increases. Meanwhile, it is clear in Fig. 3 that the thermal boundary layer of nanofluid increases in comparison with clear fluid [7].

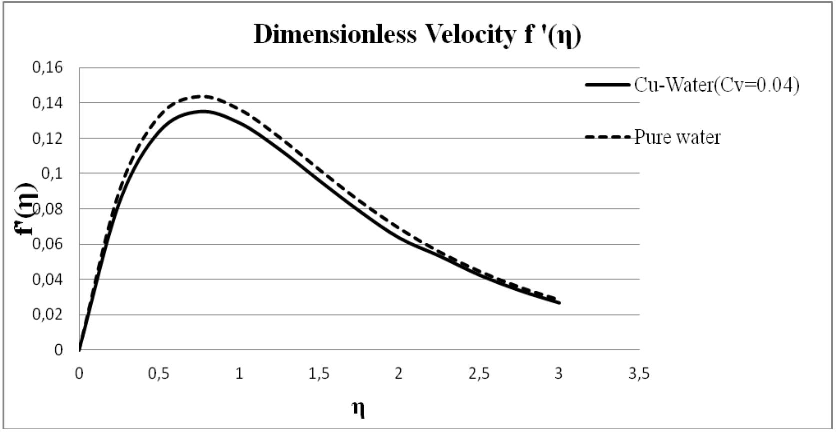

Fig. 2. Velocity profiles for clear fluid and Cu-water nanofluid at C_v=0.04.

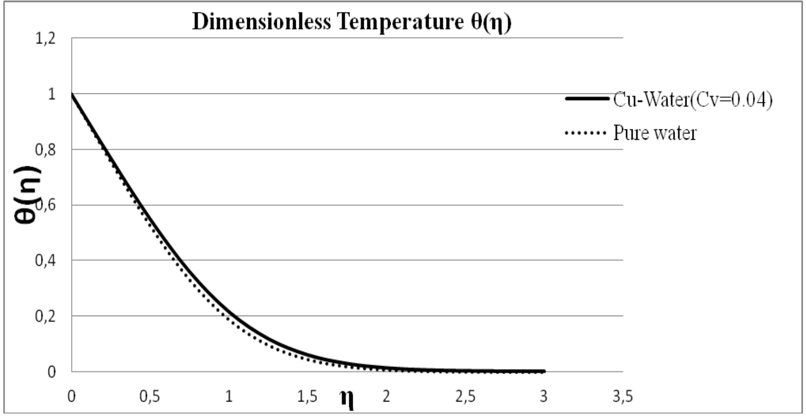

Fig. 3. Temperature profiles for clear fluid and Cu-water nanofluid at C_v=0.04.

Table 1 describes results for reduced skin friction parameter of nanofluids for various C_v in the range 0-4%. The reduced skin friction number increases with higher value of concentration. Due to greater thermal conductivity, Cu-water and Ag-water nanofluids have the highest value of reduced skin friction number as compared to other nanofluids. The reduced Nusselt numbers are performed in Table 2. With lower thermal conductivity of TiO_2, TiO_2-water nanofluid shows a smaller reduced Nusselt number. The higher concentrations of nanoparticles lead to a growth of the average Nusselt number. In the case of CuO-water nanofluid with $C_v=0.04$, reduced Nusselt number increases by 7% as compared to clear water.

Table 1

Comparison of results for reduced skin friction number $C_f = \frac{1}{(1-\phi)^{2.5}} f''(\eta = 0)$ for various C_v.

C_v	Cu	CuO	Al_2O_3	TiO_2	Ag
0.0	0.4738	0.4738	0.4738	0.4738	0.4738
0.01	0.4757	0.4756	0.4748	0.4744	0.4762
0.02	0.4777	0.4775	0.4756	0.475	0.4788
0.03	0.4799	0.4795	0.4766	0.4756	0.4815
0.04	0.4821	0.4815	0.4774	0.4762	0.4844

Table 2

Comparison of results for reduced Nusselt number Nu=$-\frac{k_{nf}}{k_f}\theta'(\eta = 0)$ for various C_v.

C_v	Cu	CuO	Al_2O_3	TiO_2	Ag
0.0	0.9777	0.9777	0.9777	0.9777	0.9777
0.01	0.9937	0.9940	0.9939	0.9909	0.9934
0.02	1.0095	1.0001	1.0102	1.0043	1.0093
0.03	1.026	1.0272	1.0267	1.0177	1.0255
0.04	1.0425	1.0441	1.0430	1.0312	1.0418

REFERENCES

1. Choi S.U.S. Enhancing thermal conductivity of fluids with nanoparticles, in: D.A. Siginer, H.P. Wang (eds.), Developments and Applications of Non-Newtonian Flows, FED-vol. 231/MD-vol. 66, ASME, New York, pp. 99-105 (1995).
2. Shenoy A, Sheremet M, Pop I. Convective Flow and Heat Transfer from Wavy Surfaces: Viscous Fluids, Porous Media and Nanofluids. New York: CRC Press; 2016.
3. Bejan A. Convection Heat Transfer. New York: Springer; 2013.
4. 4. Jaluria Y. Natural Convection Heat and Mass Transfer, Pergamon Press, U.K., 1980.
5. Brinkman H.C. The viscosity of concentrated suspensions and solutions // Journal of Chemical Physics. – 1952. – Vol. 20. – P. 571–581.

6. Maxwell J.C. A Treatise on Electricity and Magnetism, 1904.
7. Rana P., Bhargava R. Numerical study of heat transfer enhancement in mixed convection flow along a vertical plate with heat source/sink utilizing nanofluids // Commun Nonlinear Sci Numer Simulat. – 2011. – Vol. 16. – P. 4318–4334.

ОЦЕНКА ВЛИЯНИЯ СОВМЕСТНЫХ ДОБАВОК НАНОПОРОШКА ALN, ПОЛУЧЕННОГО ПЛАЗМОДИНАМИЧЕСКИМ СПОСОБОМ, И МИКРОННОГО ПОРОШКА Y2O3 НА КОНЕЧНЫЕ СВОЙСТВА КЕРАМИКИ, ОСНОВАННОЙ НА ПРОМЫШЛЕННОМ ПОРОШКЕ ALN

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Введение

Актуальной задачей силовой и микроэлектроники является увеличение эффективности рассеяния тепла [1]. Одним из наиболее распространенных способов рассеяния тепла является его отвод через подложку. Раньше в качестве материала теплоотводящей подложки использовали BeO, который обладает высокими значениями теплопроводности и диэлектрической константы [2], но из-за его высокой токсичности от него были вынуждены отказаться. Сейчас значительно распространены керамические подложки из нитрида алюминия, который помимо высоких значений теплопроводности и диэлектрической константы совершенно не токсичен [3].

Известно, что для получения высокоплотной керамики на основе AlN можно использовать модифицирующие добавки (добавки, активирующие спекание, добавки раскисляющих фтористых соединений редкоземельных металлов, углерода или активных металлов, оксидов иттрия, магния и кальция). Наиболее часто используемой из них является добавка оксида иттрия. Кроме того, считается, что даже небольшая добавка нанопорошка может значительно улучшать свойства объемных материалов. Существуют различные способы получения нанопорошков: термолиз, золь-гель метод, электрохимический метод, плазмохимические методы. Последние из них обладают следующими преимуществами: высокая скорость протекания реакции, низкие энергозатраты, высокие достигаемые энергетические параметры в процессе синтеза и высокая скорость охлаждения. Одним из таких является метод плазмодинамического синтеза на основе импульсного сильноточного коаксиального магнитоплазменного ускорителя (КМПУ) [4], разработанного в НИ ТПУ.

В данной работе рассматривается влияние совместных добавок нанопорошка нитрида алюминия, полученного плазмодинамическим способом, и коммерческого порошка оксида иттрия на конечные свойства керамики, основанной на промышленном порошке AlN марки ТЧ-1.