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Numerical Investigations on Cooling of Electronics Module with TiN, TiC and Fe Water Based Nanofluids

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Abstract – Familiar air cooling exercise is not applicable for high heat flux electronics instruments. For that, the thermal management of electronics module is very much important to its smooth operation. The present study involves an electronics module kept horizontally at the base, inside a square shaped chamber filled with nanofluid as coolant. Three different water based nanofluids, specifically Water-TiN, Water-TiC and Water-Fe, are considered as coolants in the present investigations. The numerical studies are performed to obtain the heat transfer behavior of electronics module for maintaining its temperature within the safe limit. For that, a 2D numerical model is being developed which also includes thermal buoyancy. The continuity, momentum and energy equations are solved to predict the thermal behavior. Simulations are conducted to predict the temperature fields and temperature contours. The trends of results are along the expected lines. Simulation results predicted with three different water based nanofluids are analyzed and compared for realizing the relative importance of the stated nanofluids. The key model parameter considered is heat flux of 70 W/cm^2 associated with the electronics module. The Water-TiC is observed as the nanofluid providing relatively higher cooling effect to electronics module with no such failure on account of bulk temperature.

Index Terms – Electronics Module, Simulation, Nanofluids, Water-TiN, Water-TiC, Water-Fe

1. INTRODUCTION

Latest desire of compactness of electronic items in consort with the endlessly additional high circuit densities has triggered tremendously high power densities. This tendency towards miniaturization involves high heat flux in various applications and has provided motivation, during the past several years, for significant volume of research related to the design and development of effective cooling schemes.

In view of the present trend of continual increase in both packaging and power densities in modern day's electronics gadgets, the search for the suitable cooling techniques, depending on the applications, motivated the investigators all over the world. As the common free or forced convection air cooling practice is not enough for the high heat flux uses, the chase for various methods of cooling have gathered much emphasis in recent years to overcome the challenges of high heat regarding the electronic items.

2. LITERATURE REVIEW

Webb and Ma [1] investigated about single phase liquid jet impingement heat transfer. Xuan and Roetzel [2] discussed about the conceptions of heat transfer correlation of nanofluids. Basak et al. [3] reported on effects of thermal boundary conditions on natural convection flows within a square cavity. He et al. [4] described about heat transfer and flow behaviour of aqueous suspensions of TiO2 nanofluids flowing upward through a vertical pipe. Anandan and Ramalingam [5] reviewed on thermal management of electronics. Kurnia et al. [6] analyzed numerically on laminar heat transfer performance of various cooling channel designs. Yang and Wang [7] simulated a 3D transient cooling portable electronic device using phase change material. Zhu et al. [8] optimized the heat exchanger size of a thermoelectric cooler used for electronic cooling applications. Gong et al. [9] presented numerically on layout of micro-channel heat sink useful for thermal management of electronic devices. Naphon et al. [10] epitomized on heat transfer development techniques on way for electronic items.

From the quoted studies, to the best of author' familiarity, it is realized that there is not a single full numerical investigation connecting to the influences of water based nanofluids (precisely Water-TiN, Water-TiC and Water-Fe) on thermal issues of electronics modules. With this standpoint, the present paper demonstrates numerical investigations with the stated nanofluids on thermal characteristics of electronics modules. And also, the numerical model includes additional key factors like inertia, viscosity and gravity effects apart from the usual issues concerning the present physical problem. However, the stated model ignores both compressibility and viscous heat dissipation effects. The model is very well demonstrated for the detailed numerical investigations on the influences of the already stated nanofluids (as they significantly affect the cooling characteristics) by taking electronics module heat flux and duct inlet nanofluid velocity as the important model parameters. Eventually, the model predictions with regard to the specified nanofluids are also along the expected lines.

3. DESCRIPTION OF PHYSICAL PROBLEM

The spick-and-span sketch of a standard electronics module representing the base of a square shaped chamber is demonstrated in the figure 1. It describes about the overall heat transfer from the electronics module kept horizontally at the base of square shaped chamber. The coolants considered in the present investigations are three different water based nanofluids named as Water-TiN, Water-TiC and Water-Fe. A 2D model is considered to save computation/simulation time by ignoring end effects in the transverse direction. The model includes thermal buoyancy, viscosity along with the gravity effect as well. The fluid flow is considered to be laminar and incompressible. The ambient together with the no slip boundary condition is specified at the walls. For cooling of the electronics module, a convective boundary condition in the form of heat flux is introduced at the base to simulate the overall temperature variation inside the square chamber due to heat transfer. The thermo-physical properties of stated nanoparticles in conjunction with the added system information, are briefed in table 1.

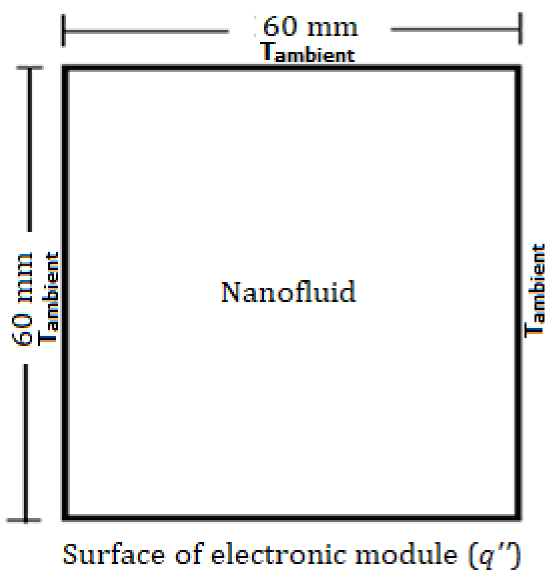

Fig 1. Schematic illustration of electronics module computational domain

Table 1. Thermophysical properties and model data

Nanoparticle Properties	TiN	TiC	Fe
Density, ρ (Kg/m^3)	5430	4930	7874
Specific heat, C_P (J/kg-K)	602	711	450
Thermal conductivity, k (W/m-K)	29.8	330	79.5

Model Data	Values
Height/Width of chamber	60 mm
Length of electronics module	60 mm
Ambient air temperature	300 K
Electronics module heat flux	70 W/cm^2

4. MATHEMATICAL FORMULATION

The concomitant physical problem is transformed into a set of governing transport equations which are solved with the associated numerical trials in relation to both modeling and simulation. The related continuity, momentum and energy equations in 2D for a fully developed hydrodynamic and thermal flow situations are described in equations from (1) to (4), respectively. The compressibility and the viscous heat dissipation effects are ignored in the existing physical situation. Instead, the thermal buoyancy factor (symbolized by $\rho g\beta\Delta T$) is incorporated in y-momentum equation (3).

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

X-momentum equation:
$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

Y-momentum equation:
$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\rho g\beta\Delta T \tag{3}$$

Energy equation:
$$\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

5. NUMERICAL PROCEDURES

5.1. Numerical scheme and solution algorithm

The concomitant governing transport equations are transformed into generalized form as follows.

$$\frac{\partial}{\partial t}(\rho\varphi)+\nabla.(\rho\mathbf{u}\varphi)=\nabla.(\Gamma\nabla u)+S \tag{5}$$

The transformed governing transport equations are discretized with the second order upwind scheme by means of a pressure based finite volume technique with the SIMPLER algorithm, where Γ denotes a transport property (k or μ), ϕ indicates any conserved parameter and S is a source term.

At the outset, both the continuity and momentum equations are solved at a time for creating the pressure and velocity fields. Subsequently, the energy equation is solved by expending the identified velocity field to get the related temperature field. In other words, all the related equations are solved all together (but not independently) in view of interdependency between the related variables.

5.2. Choice of grid size, time step and convergence criteria

An extensive grid-independence test is performed to develop the right spatial discretization, and the levels of iteration convergence criteria to be useful. As an outcome of this test, we have used 60 × 60 uniform grids for the final simulation. Corresponding time step taken in the simulation is 0.0001 seconds. Though we checked with smaller grids of 90 and 120 in numbers for 60 mm width/height of the computational domain, it is observed that a finer grid system does not alter the results significantly. In other words, the statistical data reveals that the finer grids have minor effect in the simulation results which is quite obvious from the definition of grid-independence test. Further, the smaller grid takes more computational time vis-à-vis more constancy in predictions of various fields/contours.

Convergence in inner iterations is assured only when the condition $\left|\frac{\varphi-\varphi_{old}}{\varphi_{max}}\right| \leq 10^{-4}$ is fulfilled for all variables concurrently, where φ stands for each variable u, v, and T at a grid point at the current iteration level, φ_{old} represents the corresponding value at the previous iteration level, and φ_{max} is the maximum value of the variable at the present iteration level in the whole domain.

6. RESULTS AND DISCUSSIONS

Numerical simulations are performed to investigate the influences of three different water based nanofluids (i.e. Water-TiN, Water-TiC and Water-Fe) on cooling characteristics of electronics module in terms of temperature distributions (i.e. temperature contours/fields) and surface temperatures of electronics modules. At the outset, the size of the square chamber is chosen as 60 mm. In addition, the electronics module is considered to be subjected to a heat flux of 70 W/cm^2.

6.1. Influence of Water-TiN nanofluid as coolant

With the specified model conditions, with the aim of studying the effect of Water-TiN nanofluid on the thermal behavior of the electronics module, the numerical simulations are performed, by incorporating the thermophysical properties of the specified nanofluid into the model.

Figure 2 depicts the simulated results of the temperature field (together with the colored scale bar unveiling the temperature values in terms of K) as observed at the specified model conditions by considering the Water-TiN nanofluid as coolant. The surface temperature of electronics module is found to be 341 K (which is relatively nearer to the safe limit of 356 K temperature as desired in order to avoid the thermal failure of the electronics module). As expected, the temperature of the Water-TiN nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-TiN nanofluid gradually decreases with the increase in the distance from the electronics module and then it becomes equal to the atmospheric temperature in the far field region. The related temperature contour is also revealed in figure 3. In addition, the trends of results are also along the expected lines.

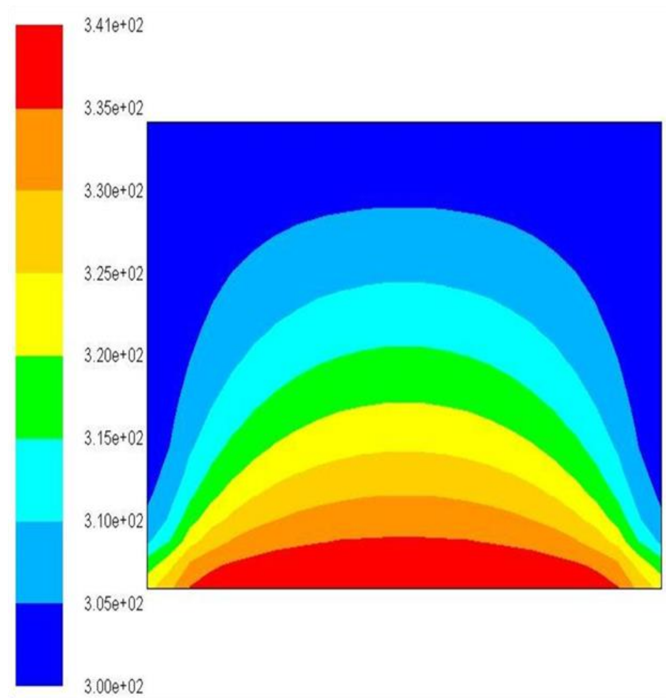

Fig 2. Temperature field with Water-TiN nanofluid as coolant

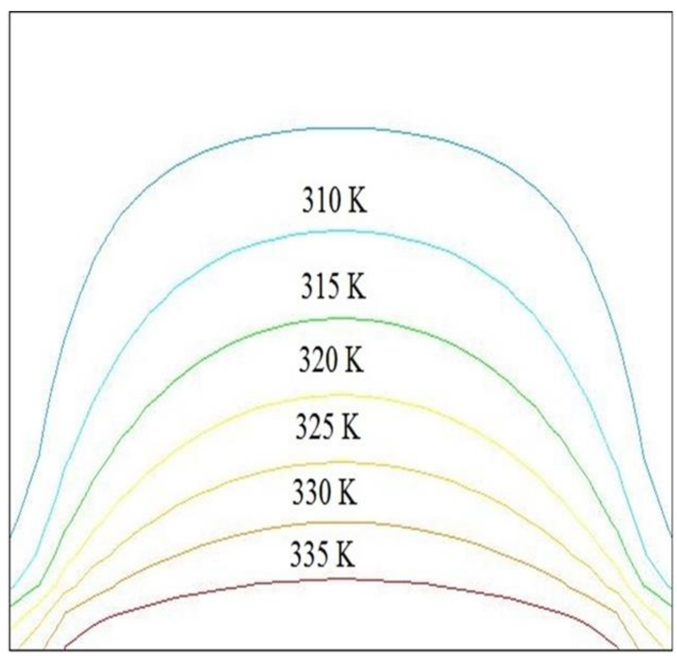

Fig 3. Temperature contour with Water-TiN nanofluid as coolant

6.2. Influence of Water-TiC nanofluid as coolant

With the specified model conditions, with the purpose of studying the effect of Water-TiC nanofluid on the thermal behavior of the electronics module, the numerical simulations are performed, by incorporating the thermophysical properties of the specified nanofluid into the model.

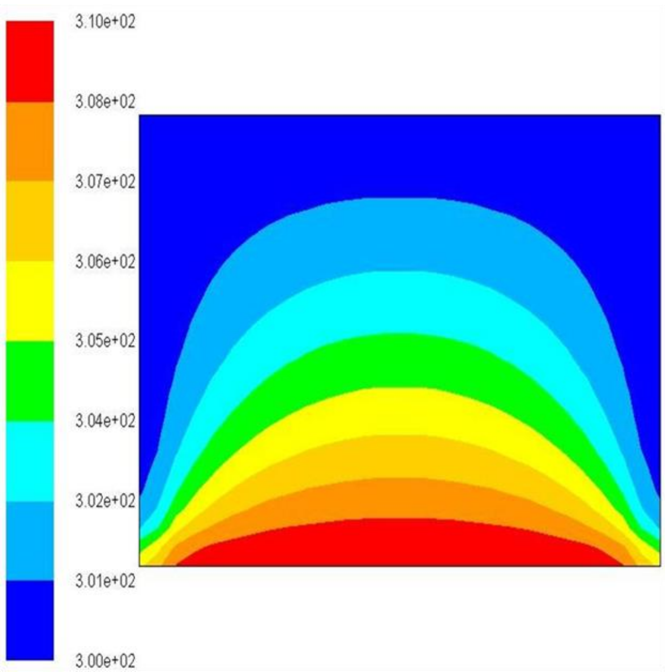

Fig 4. Temperature field with Water-TiC nanofluid as coolant

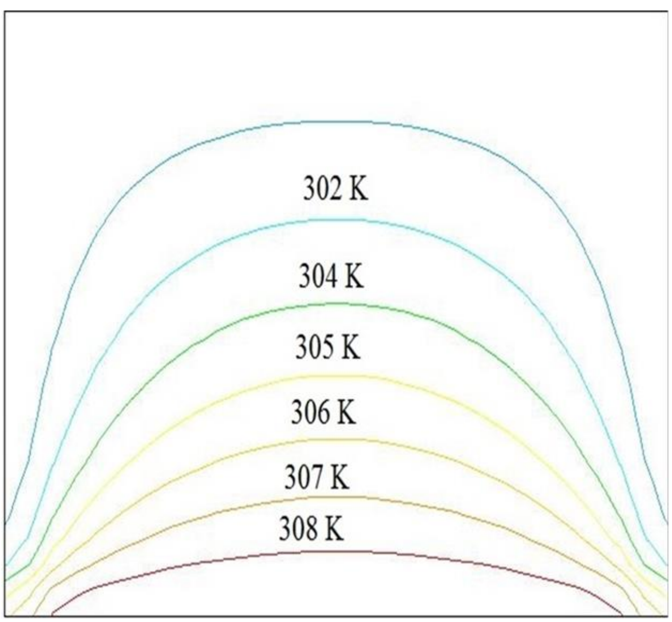

Fig 5. Temperature contour with Water-TiC nanofluid as coolant

Figure 4 illustrates the simulated results of the temperature field (along with the colored scale bar exhibiting the temperature values in terms of K) as obtained at the stated model conditions by considering Water-TiC nanofluid as coolant. The surface temperature of electronics module is found to be 310 K (which is far below the safe limit of 356 K temperature as desired in order to avoid the thermal failure of the electronics module).

As expected, the temperature of the Water-TiC nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-TiC nanofluid gradually decreases with the increase in the distance from the electronics module and then it becomes equal to the atmospheric temperature in the far field region. The associated temperature contour is also depicted in figure 5. The trends of results are along the expected lines as well.

6.3. Influence of Water-Fe nanofluid as coolant

With the specified model conditions, with the aim of studying the effect of Water-Fe nanofluid on the thermal behavior of the electronics module, the numerical simulations are conducted, by incorporating the thermophysical properties of the stated nanofluid into the model.

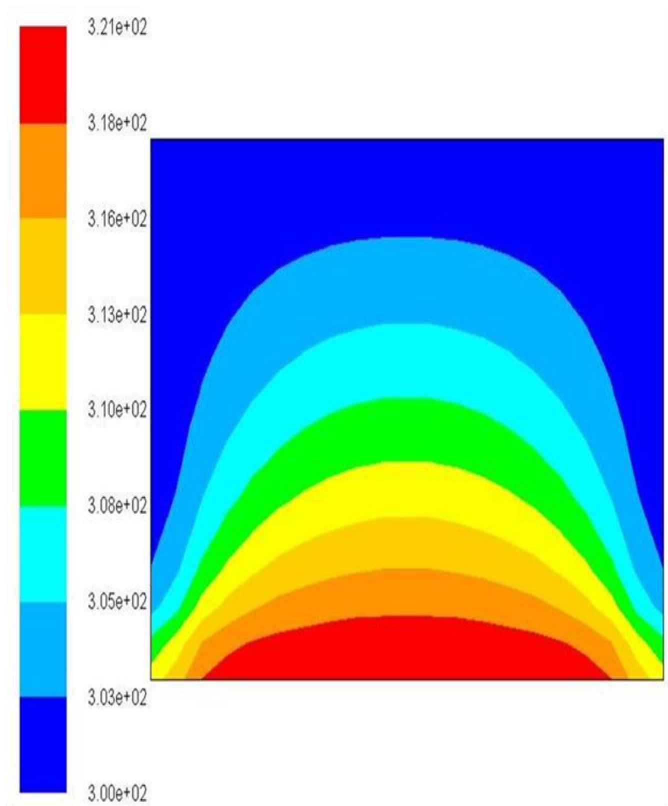

Fig 6. Temperature field with Water-Fe nanofluid as coolant

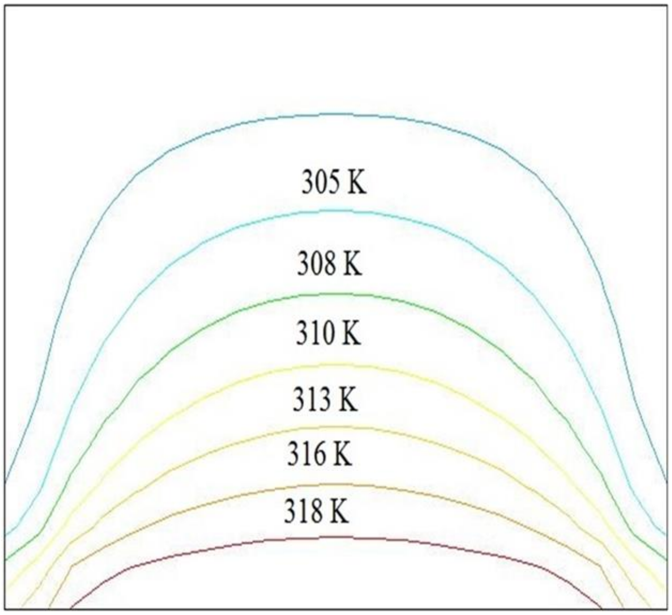

Fig 7. Temperature contour with Water-Fe nanofluid as coolant

Figure 6 elucidates the simulated results of the temperature field (alongside the colored scale bar unveiling the temperature values in terms of K) as observed at the specified model conditions by considering Water-Fe nanofluid as coolant. The surface temperature of electronics module is found to be 321 K (which is also within the safe limit of 356 K temperature as desired in order to avoid the thermal failure of the electronics module).

As expected, the temperature of the Water-Fe nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-Fe nanofluid gradually decreases with the increase in the distance from the electronics module and then it becomes equal to the atmospheric temperature in the far field region. The corresponding temperature contour is also demonstrated in figure 7. The trends of results are also along the lines of expectations.

6.4. Comparison of predicted temperatures of electronics modules obtained with different nanofluids as coolants

Table 2 recaps the numerically predicted temperatures of the electronics modules as observed by expending three different water based nanofluids (specifically, Water-TiN, Water-TiC and Water-Fe) as coolants. It is noticed that the numerical predictions/results are comparable with each other. As expected, the variations in the numerically predicted temperatures of the electronics modules are witnessed very clearly with the use of the stated water based nanofluids as coolants. This is on account of the variations in the thermal conductivities of the related nanoparticles as specified in table 1.

Table 2. Comparison of numerical predictions of electronics modules temperatures with different nanofluids as coolants.

Name of Nanofluid	Numerically Predicted Temperature of Electronics Module (K)
Water-TiN	341
Water-TiC	310
Water-Fe	321

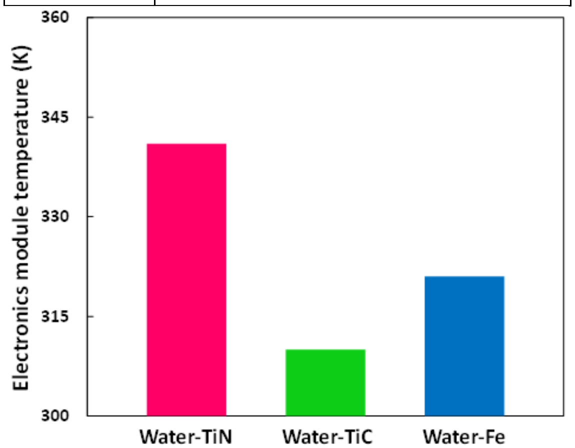

Fig 8. Variations in electronics modules temperatures with different water based nanofluids as coolants

7. CONCLUSION

A 2D computational model involving the electronics module is developed to predict the heat transfer behavior using three different water based nanofluids, precisely Water-TiN, Water-TiC and Water-Fe as coolants. The model includes additional key factors like inertia, viscosity, gravity and thermal buoyancy effects apart from the usual issues concerning the present physical problem. However, the specified model ignores both compressibility and viscous heat dissipation effects. The model is very well demonstrated for the detailed numerical investigations on the influences of the already stated nanofluids (as they significantly affect the cooling characteristics) by taking electronics module heat flux of 70 W/cm^2 as the important model parameter. The predictions of the model pertaining to the different nanofluids are along the expected lines. Direct comparison with other numerical models of electronics modules is not possible because of the absence of such models in the literature. However, the experimental comparison with an in-house experimental setup is planned for the future. With the specified model conditions, it is noticed that the Water-TiC nanofluid provides suitably apposite cooling performance without any such thermal failure and is the superior one as the electronics module temperature is far below the safe limit. Therefore, the specified model combined with the nanofluid can be used directly in industrial houses to intensify heat transfer and for electronics modules cooling.

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