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Numerical and Experimental Investigation of Solar Air Collectors Performance Connected in Series

Abstract- *In the present work, the investigation on the performance of series of solar air collectors to obtain high temperature air was performed. The first collector has been studied experimentally, while the rest of the series collectors have been investigated numerically with the same boundary conditions. The experimental and numerical results of the first collector show acceptable accruement, this lead to calculate the series of collectors numerically. The results indicated that collector's series do not work with the same efficiency. The first collector will work at low inlet air temperatures, which lead to increase in the efficiency, on the contrary for the other collectors. The results showed that, it can be determined the required number of collectors in series that necessary to obtained the required outlet air temperature.*

Keywords- collector performance; series collectors; solar air collector; efficiency.

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1. Introduction

solar energy is taken into consideration one of the maximum important alternative and renewable electricity sources that the world needs, there are several approaches to exploit this strength, which include solar air creditors, which includes four most important parts: Absorber plate that absorbs fallen upon the electricity and then lose it to the air flowing on the floor and protected with a layer or extra of window glass which lets in the transmittance of sun radiation in the course of and working to reduce warmness losses from convection to the ambient and as a result heat – trapping inside the air duct among the absorber plate and glass which lets in the passage of air above or underneath the absorber plate for the motive vital warmth absorption to heating, after which is isolated the collector of the back and sides through thermal insulation. The most essential realistic packages are heating spaces of buildings, synthetic airflow and drying timber and agricultural products in addition to its use, in observed with conjunction with PV panels to generate strength and heat. The primary drawback of solar air creditors is the necessary to coping with comparatively extensive volumes of air with low heat capacity as operating fluid. The classification of flat plat collectors can be in to types (hydronic) collectors. Water and air collector use air and water as the heat transfer fluids [1].The practical applications simplest of the sun is the air heating collector where have many advantages such as make simple, cheap, friendly to environmentally and used in agricultural production drying. The types of these collectors are: the single passes with front duct, rear duct, double duct and double pass [2]. The higher heat loss is when the available of area to the heat transfer is not larger than the area of projected to the absorber therefor becomes of unnecessary to hot absorber [3–4]. The efficiency of solar collector based on the material of collector covered; absorber and its position and the air speed in the collector [5–6]. The collectors of solar air based on many criteria, such as: type of cover, materials of absorber, absorber shape, flow pattern of absorber and shapes of flow, passive and active types implying free and forced convection [7–8]. The low of thermal efficiency consider one problem in the collectors of solar air due to low ability of heat transfer plate of absorber and flowing of air in the duct. The thermal efficiency in the collectors of solar air can be improving by increasing coefficient of heat transfer and make it economic more [9–10]. The types of connection used in the collectors of solar air such as series, parallel and parallel–series. Some problems such as heat losses and pressure drop can be occurred in parallel connection. The

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system becomes optimized in several countries when using mixed connection of series and parallel or the connections in series as well as the effect of the fluid distributions must be taken into account [11–12]. The energy efficiency decreases continuously with increasing surface of collector in series of the solar flat plate collectors [13-14]. In parallel connection, the total mass flow rate from the storage tank divided into many flows and the outlet temperatures of water are similar. The maximum of efficiency and economy obtain in parallel connection of solar air collectors, [15–16]. The identification of heat transfer in collectors of solar air with roughness leads to increase in pressure drops, [17]. The flow characteristics prediction by using CFD code simulation, which is considered an effective tool to estimate momentum and heat transfer rates. In this type of process, equipment leads to the rapid development of computational tools. Consequently, as CFD more widely used in engineering design, it is becoming of essential importance to know how reliably the flow features and the hydrothermal behavior can be reproduced in such air veins. Numerical simulation tools into the collector of solar air region area analyzed the performance characteristics of the unglazed transpired collector of solar air and compared them with many kinds of traditional collectors of solar air. The results showed that the unglazed transpired collector of solar air has unparalleled advantages in the ventilation preheating region and proves that CFD tools have their own advantages in the collector of solar air research region [18]. The reviewing of the previous studies shows that there is a shortage in studies of series of collectors. Numerical and experimental study of series of collectors will be carried in this work. The objectives of the present study are: investigate the solar collectors performance connected is series, the optimum choice to the number of solar collectors, and to find outlet temperature with time in sunlight of day.

2. Mathematical Modeling

I. The governing equations

The CFD model of the flow within solar collector is depicted by turbulent flow and obtained by numerically determination the governing 3D elliptic PDEs (partial differential equations). The simulations were conducted employing a FORTRAN language. The general partial differential equations [19] for continuity, momentum, temperature and turbulence model k, ε all have the form:

$$\frac{\partial}{\partial x}(\rho U\varphi)+\frac{\partial}{\partial y}(\rho V\varphi)+\frac{\partial}{\partial z}(\rho W\varphi)=$$
$$\frac{\partial}{\partial x}\left(\Gamma_{\varphi}\frac{\partial\varphi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_{\varphi}\frac{\partial\varphi}{\partial y}\right)+\frac{\partial}{\partial z}\left(\Gamma_{\varphi}\frac{\partial\varphi}{\partial z}\right)+S_{\varphi} \quad (1)$$

Where ϕ represents the independent variable and therefore the three expressions on the left side are convection terms and therefore the four expressions on the right side are diffusion and supply expression. During this equation, Γe is that the diffusion coefficient (diffusivity) that is given by:

$$\Gamma_e=\frac{\nu_e}{\sigma_e}+\frac{\nu_t}{\delta_t} \quad (2)$$

Where: σe is that the effective Prandtl variety together with the turbulent coefficient and turbulent diffusion coefficient. The supply expression showing within the on top of governing equation is given within the Table 1.

II. Boundary Conditions

A. Inlet Boundary Conditions

Figure 1, Indicate the schematic diagram of the model and coordinate system. The inlets boundary conditions for the CFD domains, the distribution of all vectors and scalars variables (i.e.; U, V, W, T, ω_a, k and ε) is specified or estimated. The inlet boundary condition can be written as:

$U(0,y,z)=U_{in}$, $T(0,y,z)=T_{in}$,
$V(0,y,z)=0$, $k(0,y,z)=k_{in}$,
$W(0,y,z)=0.$, $\varepsilon(0,y,z)=\varepsilon_{in}$

B. Outlet Boundary Conditions

The usual practice at the outlet section is to set normal gradients to zero. The outlet boundary conditions can be written as:

$$\frac{\partial\phi(x,y,z)}{\partial x}=0 \quad (3)$$

The simulation was carried for four collectors in series. For first collector, the results were compared with experimental results. The air inlet boundary condition for the second, third and fourth collectors are the outlet air temperature of the previous collector. The temperatures of the absorber and glass of the second, third and fourth collectors are the same of the first measured collector.

Table 1: Source term in the governing PDEs) [21].

Equation	ϕ	Γ_ϕ	S_ϕ
Continuity	1	0	0
U-momentum	U	ν_e	$-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left(\nu_e\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_e\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial z}\left(\nu_e\frac{\partial W}{\partial x}\right)$
V-momentum	V	ν_e	$-\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left(\nu_e\frac{\partial U}{\partial y}\right)+\frac{\partial}{\partial y}\left(\nu_e\frac{\partial V}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu_e\frac{\partial W}{\partial y}\right)$
W-momentum	W	ν_e	$-\frac{\partial P}{\partial z}+\frac{\partial}{\partial x}\left(\nu_e\frac{\partial U}{\partial z}\right)+\frac{\partial}{\partial y}\left(\nu_e\frac{\partial V}{\partial z}\right)+\frac{\partial}{\partial z}\left(\nu_e\frac{\partial W}{\partial z}\right)$
Temperature	T	Γ_e	0
Kinetic energy	k	Γ_k	G-ε
Dissipation rate	ε	Γ_ε	$C_{1\varepsilon}\frac{\varepsilon}{k}G-C_{2\varepsilon}\frac{\varepsilon^2}{k}$

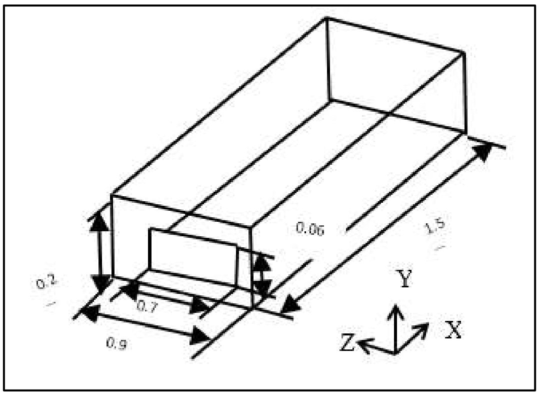

Figure 1: Schematic diagram and coordinate system

3. Experimental Study

Figure 2 shows schematic of the first solar collector of flow type above absorber and single glazing. The body of collector is made of sheet steel with dimensions 1.5m X 0.9 m and height of 20 cm. The photo of first solar air heater collector is shown in Figure 3. The entry and exit of air have dimensions 6 cm x 70 cm. The penetrated transparent surfaces of the solar radiation have dimensions 1.5 m X 0.9 m and thickness 3mm. The dimensions of the absorber surface of 1.5 m X 0.9 m is insulated from the right and left by thermal insulation and the net area of the absorber are 0.8 m X 1.5 m made of coated solid sheets with dark black non – glossy. The collector was exposed to solar radiation after being placed on tilt angle of 35^o. The selection of this angle according to the location of the town and any day of the year to confirm the accomplishment of the incidence angle is equal to zero (incidence angle θ = 0) that is perpendicular to the solar radiation absorber surface of the plate as shown in Figure 4. A fan was used to push air through thermally insulated flexible tube and the tube extends from the fan to the air entry opening in the collector. Numerically, a chain created of four collectors and is shown in Figure 5. The angle of orientation, the collector was set at 35 degrees to capture solar radiation. Increases the solar density from morning and reached to the maximum at noon then begins decreases at the evening. Air in solar air heater passed through a space between the absorber plate and cover glass. Thermal efficiency of solar collector systems is defined as the ratio of useful energy gain by the air to solar radiation incident on the absorber of solar collector.

$$\eta = \frac{Q_{uesful}}{Q_r} \mathrm{X}100 \quad (4)$$

$$Q_{uesful} = \dot{m}C_p\,(T_{out} - T_{in}) \quad (5)$$

$$\dot{m} = \rho\, A\, U \quad (6)$$

$$Q_r = I\, A_c \quad (7)$$

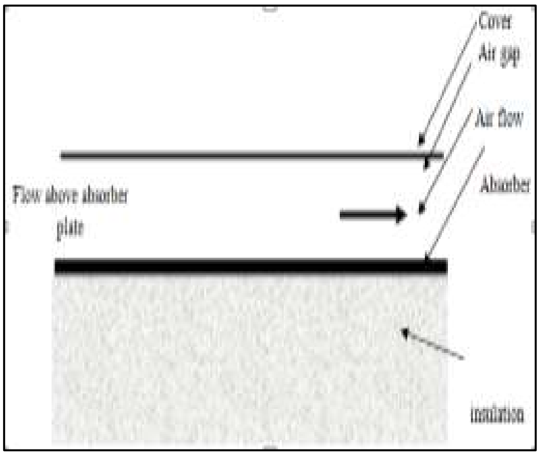

Figure 2: Schematic absorber plate of solar air collector

Figure 3: Photo of experimental rig collector: (1) Frame, (2) glass cover, (3) side wall of the frame, (4) insulation (glass wool), (5) absorber, (6) channel for air flow, (7) rear wall.

Figure 4: View of setup of solar air heater collector with fan

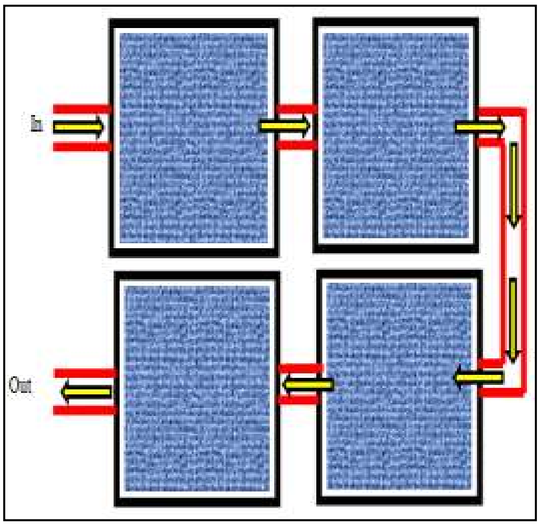

Figure 5: Series of four collectors

4. Results and Discussion

The experiments were conducted on the solar collector at 16 – 5 – 2015 in Baghdad, the daylight hours was bright for the period of (7–17) am, the tilt angle of the collector is 35^o and speed of air flow inside of the collector is 1.5 m/s as well as the inlet air velocity U was changed in range (1 – 2.5) m/s. The temperatures of the air, glass and absorber were measured experimentally and numerically while the rest of the series of the system collectors were calculated numerically by CFD. The variation of solar radiation were measured by solar radiation measuring instrument with daylight hours and is shown in the Figure 6. At the beginning of the day, the radiation is low, gradually increases until peak up at midday, and then gradually decreases until the fall to the lowest level at sunset. Figure 7 shows the temperature-measuring instrument of the ambient air, glass and surface absorber. The temperature increases with increasing the hours of the day and become the highest in the middle of the day. The increasing of temperature depends on the radiation values. The absorber surface converts solar radiation to thermal energy, as well as this figure indicated absorbent surface temperature is higher the other due to high absorbance of black dark surface. The temperature of glass surface was less than absorber plate temperature. Figure 8 shows the outlet temperature of the air experimentally and numerically in the first collector. This figure indicated that the outlet temperature increases with the hours of the day and become the highest in the middle of the day. The outlet temperature of the air depends on intensity of solar radiation. Numerically, the highest outlet temperatures of the air of the first collector to fourth collector were 42 °C, 46 °C, 49 °C and 52 °C respectively. Figure 9 indicated the thermal efficiency of numerical solutions of the each collector where it appears that the first collector is high efficiency and decreasing efficiency with increasing the number of collectors due to the temperatures difference decreasing at the entry and exit (output energy) with constant values of the solar radiation (input energy) that are equal to all collectors. Figure 10 depicted the decreases of the efficiency with increased number of collectors because of the maximum of temperatures distinction in within the first collector and gradually decreases as increased the number of collectors. Figures. 11, 12, 13 depicted the variation of air outlet temperature with length of collector at 9 am, 12 pm and 3pm. These figures indicated that air temperature, which flows inside the collector increases with length of collector, the reason, is heat transfer by convection from the surface absorber of solar radiation into the air that flows inside the collector. These figures illustrate that the highest outlet temperatures of the air in the fourth collector is 35°Cat 9 am, 46°C at 12pm and , 43°C at 3pm. Figure 14 shows numerical flow field and isotherm for time = 01:00 pm. In (a) the flow field shows the boundary layer clearly at z = 0.4 m. In (b) the isotherm contours show the increasing of temperature within the flow as x increases. The penetration of temperature through the flow does not reach the core of the flow which means the thickness of 7 cm must be decreases and 5 cm is seems more suitable for this case.

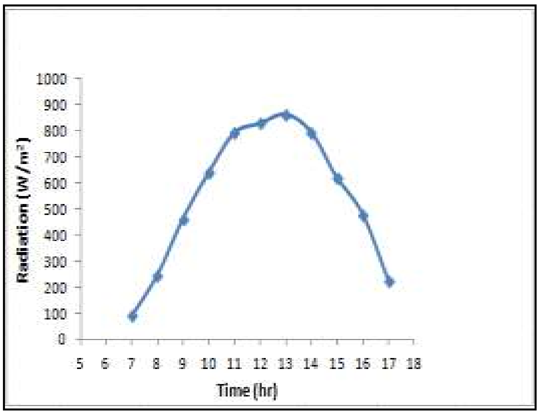

Figure 6: Solar intensity with time in Iraq (Baghdad)

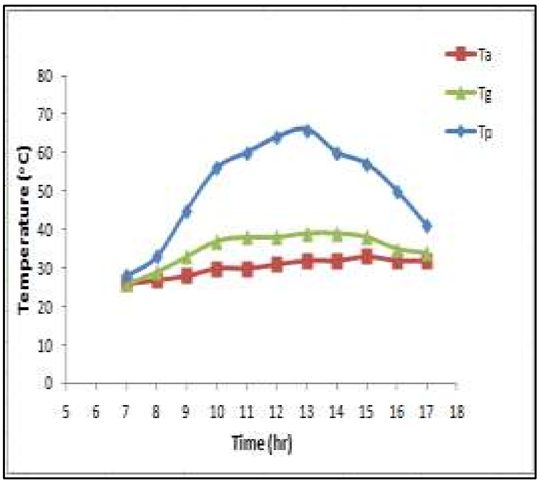

Figure 7: Measured ambient air, glass, plate absorber temperature during the day

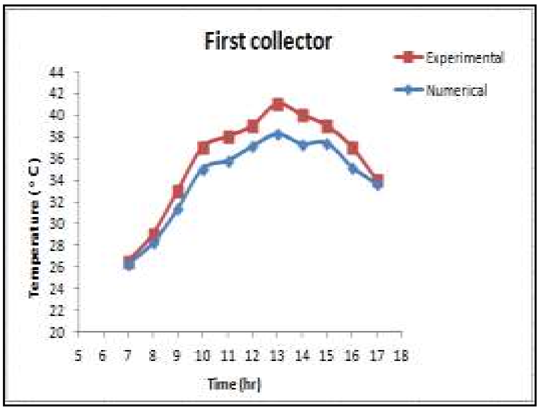

Figure 8: Variation of experimental and numerical air outlet temperature in first collector with time

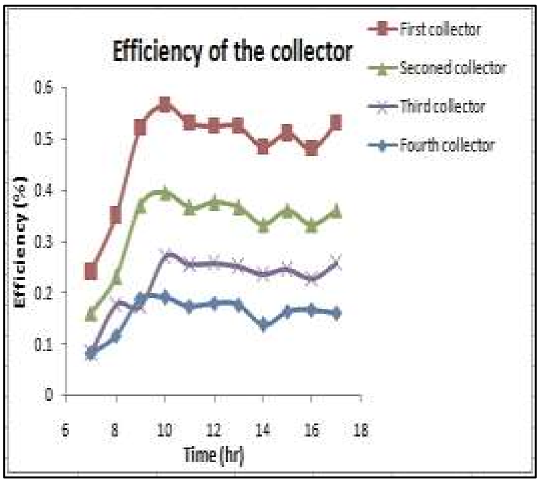

Figure 9: Efficency Variation for first second,third and fourth solar collectors with time

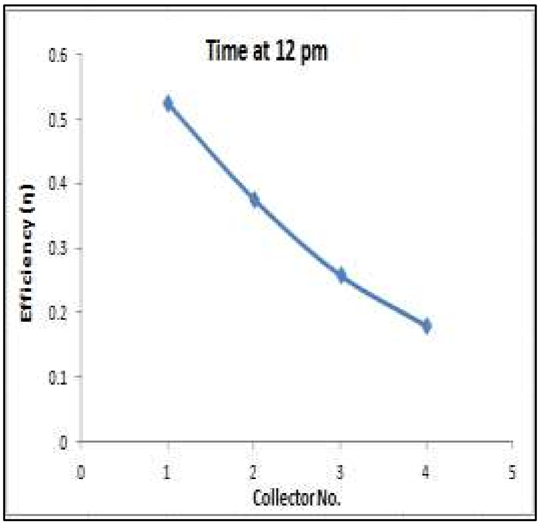

Figure 10: Variation of Efficency with length number of collector

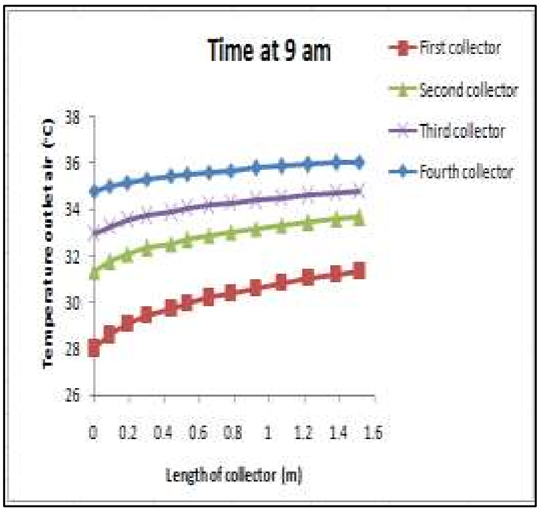

Figure 11: Variation of air outlet temperature with length of collector at 9 am

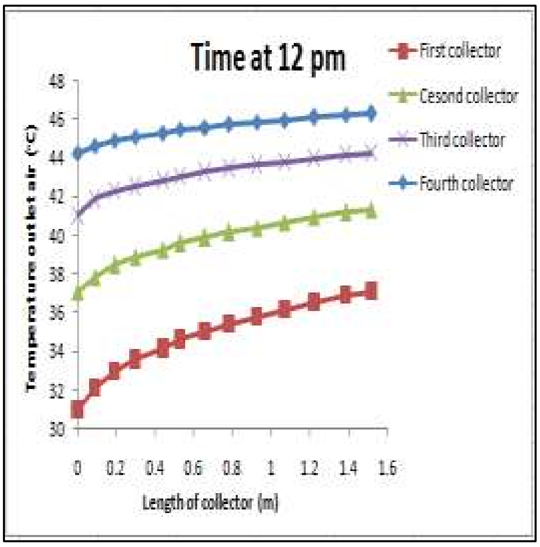

Figure 12: Variation of air outlet temperature with length of collector at 12pm

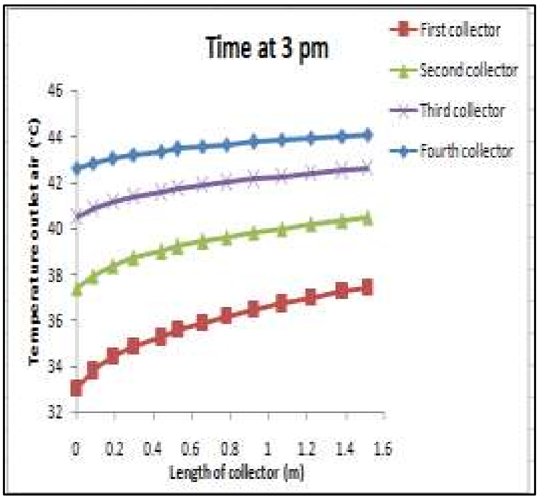

Figure 13: Variation of air outlet temperature with length of collectors at 3pm

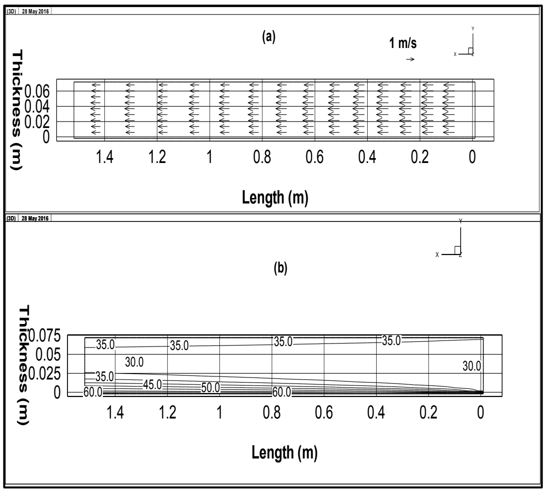

Figure 14: Numerical flow field and isotherm contours; a) flow field, b) isotherm contours for u_{in}=1.5 m/s, T_p = 66 C, T_g= 39 C.

5. Conclusions

1. The collectors of series connected do not work with the same efficiency. The collector efficiency was decreases in the series while in the parallel system, the efficiency was constant because of the temperature distinction between the entry and exit of air are equally for all panels (collectors) system.
2. The increase of number of solar collectors in the series leads to increase the temperature of the hot air to a certain limit.
3. In the series system, high temperature can be obtained by increases the number of collector, while in parallel system the temperature of air exit was constant.
4. The impact of absorbent and glass does not reach the core, it is counseled to use 5 cm thickness rather than7 cm.

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