Preliminary SWCNTs-kerosene on Carreau MHD flow over a wall with distinct thickness

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Abstract. The Magnetohydrodynamics (MHD) Carreau over a stretched surface on a kerosene oil based is examined in this paper. Most specifically, we extended and reported the effects of various parameter namely; magnetic field, thermal radiative and heat generation on the temperature. Thermal conductivity enhancements of water and seawater in the presence of single-walled carbon nanotubes (SWCNTs) are presented. We used transformation of similarity to reduce and regenerated the partial differential equations (PDEs) into ordinary differential equations (ODEs) for the nonlinear governing equation alongside with their related boundary conditions. The result of the regenerated ODEs is solved numerically by the application of the fourth/fifth order Runge Kutta Fehlberg technique with method of shooting using Maple code. The result obtained indicated that there is significant positive correlation between high electric field. The result reported that the temperature parameter is decreased with all parameter when the electric is high (El=0.5), which indicated that the electric filed is a dominant of SWCNTs-kerosene.

This study was conducted to develop and study the performance of a Photovoltaic Thermal (PVT) system technology, a system which combines the Photovoltaic (PV) system with a solar thermal (T) system that produces electricity and hot water simultaneously. The objective of this study is to develop a working prototype of the PVT system for roofing system application with water as the cooling agent. A polycrystalline PV cells was used as the solar collector while a transparent rubber tube was attached at the backside of the PV panel with water flowing directly from a water tap source. Two designs were examined for the heat absorber design which was categorized as the parallel and spiral flow design. The system was run at an open space to simulate real life application. A working PVT system was developed; however an electrical efficiency drops 0.3% and 1.07% on the parallel and spiral design respectively when compared to the standard PV system.

1. Introduction
Stephen Choi, in 1995, introduced the term nanofluid [1]. The term is described as a liquid that contain dispersion of submicronic solid particles and the particle that contains the nano is called nanoparticles. The fundamental objective of using of nanoparticle is to diffuse solid particles in the fluid to boost thermal conductivity. In real-time application, nanofluid has been reported to be boosting the transfer of heat than 50 percent especially when the nanoparticle volume ratio of the base-oil is below 0.3 percent [2]. The apparent (surface) region to the ration of the volume of nanoparticle is very huge. This however, fetches a huge and enormous propelling pressure for diffusion, most
specifically when the temperature is raised. When comparing nanofluid with other based fluid, nanofluid has an upper hand about boosting in thermal conductivity [3], [4], [5], [6]. Heat transfer enhancement through modification of fluid thermo-physical properties by adding dispersed particles to a base fluid has been a topic of interest since the early works by Ahuja as indicated in [7]. With the new discovery in thermal conductivity, many researchers have carried out research activities to improve the thermal conductivity properties so that it would behave same as fluid but has thermal conductivity as metal by adding conductive solids into fluids, [4], [8], [5], [6], [3]. Nanoparticle used are usual made of metal (Al, Cu), [9], oxides (Al2O3) [10] and SWCNTs [11] just to mention a few. Therefore, because of the new additive it is very important and necessary to explore more on the impact of heat transfer behaviour and characteristics, namely, thermal conductivity, heat transfer, viscosity and so on.

In this research direction, mathematicians, physicists and engineers are among the academic researchers who contribute to the knowledge of thermal conductivity [12], [13], [1]. Though, research has shown that nanofluid provides higher transfer of heat with respect of the based fluid [14], [15], [16] but regarding the kerosene-based research direction, it is observed that only scanty research have been reported with respect to the nanofluid thermal particles [17]. Various nanoparticle shapes have been utilized over the experiment [18], [19], which presented the first kind of experimental analysis. The thermal conductivity improvement is due to the shape of the included nanoparticles into suspension. [20] analyzed the role of the silicon carbide (SiC) nanoparticles where they admitting the shape affirm disc or platelet and consistently diffused in water on mechanical assets and thermal conductivity enrichment.

Recent, report reviewed that one of the essential outputs of the existences of the powerful electrical conductivity promotes a distinguishable and distinctive subject matter on the fluid SWCNTs flow. In industrial applications, nanoparticles have been used to avoid overheat of the instrument [21]. Thus, nanoparticle play an important role as the coolant substance to transfer heat example of such is our computer system [22]. The heat sink helps to absorb and cool the heat generated in the system, thereby avoid being overheated. This is because the diameter less than 100nm and this condition will affects the properties of the liquid surface area to enhance the heat transfer compare to the micron-size particle [23]. As far as development in technology and industries remain, the exchange of thermal conductivity must be updated time to time. The old method thermal conductivity, which is referred to as traditional means of transferring heat fluid such as Maxwell theories [24] has allot of difficulties in improving the cooling capacities [25], [26], [27], and is not sufficient or cannot explain behaviour of the thermal conductivity of nanoparticle. However, recently, effort has been carried out to improve and report the thermal conductivity’s property by making an adding into the based fluid [28]. A few shapes of the nanoparticles that have been analyzed include cylindrical-shape [9], [18], and shuttle-like shape [29].

In this paper, our aim is to extend and explore more on the effects of various parameter namely; magnetic field, thermal radiative and heat generation on the temperature and to report the effects of various parameters in thermal conductivity of the nanofluid to kerosene based SWCNTs.

Methodology

2. Mathematical formation

The aim of this work is to clarify several aspects of a mathematical form and report Carreau SWCNTs – kerosene flow of nanofluid attributed of nonlinear of the stretching with extensible depth. 

\[
U_{0} = U_{0}(x + b)^{m} \]

is the velocity used in the paper to construct the stretching sheet, where \( U_{0} \) represents the source velocity for the constructed sheet. \( B_{0}(x + b)^{(1-m)/2} \) is set to be the thickness of sheet. \( b, m \) are set to be its constant dimensionless and the rate of power law directory, respectively. The review of the model is constructed to be pleased only for \( m \neq 1 \), the reason is that of for \( m = 1 \), the issue lessen the flat-sheet. Flexible strength of the magnetic field \( B_{0}(x) \) is vertically imposed to the
plate. On the other hands, the electrical and field of the magnetic is perpendicular to the surface which deferent thickness. Fig. 1 displayed the physical configuration of SWCNTs – kerosene nanofluid as used in this paper.

![Diagram](image)

**Figure 1.** Physical configuration of SWCNTs – kerosene nanofluid system.

System based on the boundary layer approximation, equations (1) - (4) can be derived:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  

(1)

\[
u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{\mu_{nf}}{\rho_{nf}} \left( \frac{\partial^2 u}{\partial y^2} + \frac{3(n-1)}{2} \Gamma \frac{\partial u}{\partial y} \frac{\partial^2 u}{\partial y^2} \right) - \frac{\sigma_{nf}}{\rho_{nf}} (E(x)B(x) - B_0^2(x)u)
\]  

(2)

\[
u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{k_{sf}}{(\rho c_p)_{nf}} \left( \frac{\partial^2 T}{\partial y^2} \right) - \frac{1}{(\rho c_p)_{nf}} \frac{\partial q_f}{\partial y} + \frac{1}{(\rho c_p)_{nf}} \left[ \left( \frac{D_B}{T} \right) \frac{\partial T}{\partial y} \frac{\partial T}{\partial y} \right] + \frac{Q_B(T - T_w)}{(\rho c_p)_{nf}}
\]  

(3)

\[
u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = \frac{(D_C)}{T} \frac{\partial^2 C}{\partial y^2} \left( \frac{\partial^2 T}{\partial y^2} \right) + \frac{(D_B)}{T} \frac{\partial^2 T}{\partial y^2} \frac{\partial^2 T}{\partial y^2} - K(C - C_w)
\]  

(4)
Subject to the boundary conditions

\[
\begin{align*}
&u(x, B(x + b)^{(1-m)/2}) = U_o(x + b)^m; \quad v(x, B(x + b)^{(1-m)/2}) = 0; \\
&T(x + B(x + b)^{(1-m)/2}) = T_w \left[ x + B(x + b)^{(1-m)/2} \right] = C_{w}; \quad u(x, \infty) \to 0; \quad T \to T_o; \quad \mathcal{C} \to \mathcal{C}_o \text{as } y \to \infty
\end{align*}
\]

(5)

| Parameters                        | Symbols | parameters | Symbols |
|-----------------------------------|---------|------------|---------|
| Magnetic field factor            | \(B(X) = B_0(x + b)^{(1-m)/2}\) | electrical field factor | \(E(X) = E_0(x + b)^{(1-m)/2}\) |
| Electrical conductivity          | \(\sigma\) | nanofluid temperature | \(T\) |
| Concentration of the nanofluid near the wall | \(C_w\) | Ambient concentration of nanofluid | \(C_{\infty}\) |
| Nanofluid effective density     | \(\rho_{nf}\) | Nanofluid thermal diffusivity | \(a_{nf}\) |
| Nanofluid dynamic viscosity     | \(\mu_{nf}\) | nanofluid heat capacitance | \((\kappa_p)_{nf}\) |

Table 1 displayed the parameters with its respective symbols used in this article for ease identification.

\[
\begin{align*}
\rho_{nf} = & (1-\zeta)\rho_f + \zeta \bar{\rho}_s, \\
\mu_{nf} = & \frac{\mu_f}{(1-\zeta)^{1/2}}, \\
(\rho c_p)_{nf} = & (1-\zeta)(\rho c_p)_f + \zeta (\rho c_p)_s, \\
\alpha_{nf} = & \frac{k_{nf}}{(\rho c_p)_{nf}} = \frac{k_{nf}}{k_f} \frac{k_f}{(k_s + (l-1)k_f) + \zeta (k_f - k_s)}, \\
\sigma_{nf} = & (1-\zeta)\sigma_f + \zeta \sigma_s, \\
(D_b)_{nf} = & (1-\zeta)(D_b)_f
\end{align*}
\]

(6)

The Maxwell design method was used to determine the dynamic thermal or electrical conductivities of liquid-solid suspensions. Let \(\sigma_f\) and \(\sigma_s\) be the base fluid and nanoparticle electrical conductivities, \(k_f\) and \(k_s\) are the base-fluid, and nanoparticle thermal conductivities, \(\zeta\) is the volume fraction of nanoparticle, \(\rho_f\) and \(\rho_s\) are the base fluid and nanoparticle densities, \(\sigma_f\) and \(\sigma_s\) are the based fluid, and nanoparticle electrical conductivities, \(\mu_f\) is the base-fluid dynamic viscosity, \(k_{nf}\) is the nanofluid effective thermal conductivity, \(q_r = -4\sigma_r\sigma T^4 / 3k^2\) \cite{30} is the Rosseland’s dissipation for the radiative heat flux, \(k^2\) is the Rosseland signify absorption coefficient and \(\sigma^*\) is the Stephen-Boltzmann constant. Here the term \(T^4\) is linearized using Taylor’s series about \(T_o\) as \(T^4 = 4T_o^4 + \sigma^* T^2 - 3\sigma o^4\). The similarity conversions were performed as below:
\[ \psi = \left[ \frac{2v_J U_0(x + b)^{m-1}}{m+1} \right]^{\frac{1}{2}} f(\eta), \eta = \left[ \frac{(m+1)U_0(x + b)^{(m-1)}}{2v_f} \right]^{\frac{1}{2}} \quad y, \theta(\eta) = \frac{T - T_w}{T_w - T_n}, \phi(\eta) = \frac{C - C_w}{C_w - C_n}, \]  

(7)

where \( \nu_f \) is the fluid kinematic viscosity and \( \psi \) is the function \( u = \frac{\partial \psi}{\partial \eta}, v = \frac{\partial \psi}{\partial x} \).

Therefore, the dimensionless form of Equations (1) - (4) as follow

\[ F\left(1 + \left(\frac{3(n-1)}{2}W^2(F^*)^2\right)\right) + G.B\left(\frac{2m}{m+1}F^2 - FF^*\right) + G.A.M(E_1 - F^{*2}) = 0 \]  

(8)

\[ \theta^* + Pr_J EF\theta^* + (Al)Nb\theta^* + (Al)Nt\theta^2 + \lambda \theta = 0 \]  

(9)

\[ \phi^* + (Al)\left(\frac{1}{(Al)} Nb\theta^* + LeF\theta^* - Le\phi\right) = 0 \]  

(10)

Subject to the boundary conditions:

\[ F(\alpha) = \alpha \frac{1-m}{1+m}, F'(\alpha) = 1, \theta(\alpha) = 1, \phi(\alpha) = 1; F'(\infty) = 0, \theta(\infty) = 0, \phi(\infty) = 0 \]  

(11)

\[ \kappa_f = (k_f + (e-1)k_f) - (e-1)\zeta(k_f - (k_f)) \quad K_f = (k_f + (e-1)(k_f) - \zeta(k_f - (k_f)) \quad B = \left[ \frac{1 - \zeta + \zeta \rho_f}{\rho_f} \right], \quad T = \frac{K_{nf}}{K_f} \]  

(12)

\[ E = \left(1 - \zeta + \zeta \frac{\rho_f(c_p)_s}{\rho_f(c_p)_f}\right), \quad A = \left[ 1 + \frac{3}{\frac{\sigma_s}{\sigma_f} - 1} \right] \quad \right\{ \frac{\sigma_s}{\sigma_f} + 2 \right\} - \left[ \frac{\sigma_s}{\sigma_f} - 1 \right] \]  

(13)

\[ \alpha = B \sqrt{\frac{U_0(m+1)}{2v_f}}, \quad \eta = B \sqrt{\frac{U_0(m+1)}{2v_f}} \]  

Here, \( \eta \) is the depth parameter of the corresponding wall and \( \alpha \) is the surface dependent plate. By substituting, \( f(\alpha) = f(\eta - \alpha) = f(\eta), \theta(\alpha) = \theta(\eta - \alpha) = \theta(\eta), \) and \( \phi(\alpha) = \phi(\eta - \alpha) = \phi(\eta) \), the above equations can be rewritten as:

\[ F\left(1 + \left(\frac{3(n-1)}{2}W^2(F^*)^2\right)\right) + G.B\left(\frac{2m}{m+1}F^2 - FF^*\right) + G.A.M(E_1 - F^{*2}) = 0 \]  

(14)
\[ \theta^* + Pr_f, E \left( \theta + (Al) Nb \theta' \phi' + (Al) Nt \theta'^2 + \lambda \theta \right) = 0 \]

\[ \phi^* + (Al) \left( \frac{1}{Nb} \theta^* + Lef \theta' - Le \theta' \phi \right) = 0 \]

(15)

(16)

with boundary conditions:

\[ f(\alpha) = \frac{1 - m}{1 + m} , f'(\alpha) = 1 , \theta(\alpha) = 1, \phi(\alpha) = 1; f'(\infty) = 0, \theta(\infty) = 0, \phi(\infty) = 0 \]

(17)

\[
M = \frac{2\sigma_f B_0^2}{U_0 (m+1)(x+b)^{m-1} \rho_f} \quad \text{is the magnetic parameter,}
\]

\[
W = (m+1) \frac{U_0^3 (x+b)^{3m-1}}{2 v_f} \Gamma^2 \quad \text{-is the}
\]

\[
Pr_f = \frac{Pr}{\left( \frac{k_{of}}{k_f} + \frac{4}{3} R \right)} \quad \text{Weissenzberg number,}
\]

\[
Pr = \frac{\left( \frac{k_{of}}{k_f} + \frac{4}{3} R \right)}{k_f} \quad \text{-is the Prandtl number,}
\]

\[
\gamma = \frac{2K}{U_0 (m+1)(x+b)^{m-1}} \quad \text{Re}_s = \frac{xU_0(x)}{v_f} \quad \text{-is the chemical reaction,}
\]

\[
E_i = \frac{E_0}{R_0 U_0 (x+b)^m} \quad \text{N_b = (\rho c)_w (D_B)_f (C_w - C_e)} \quad \text{-is the local Reynolds number,}
\]

\[
N_i = \frac{(\rho c)_w (D_B)_f (T_w - T_{\infty})}{(\rho c)_p v_f T_{\infty}} \quad \text{Le =} \frac{v_f}{(D_B)_f} \quad \text{-is the Brownian motion parameter,}
\]

\[
R = -\frac{4\sigma \kappa T^3_{\infty}}{k_f k^2} \quad \text{-is the thermophoresis parameter,}
\]

\[
Re_{T_f}^2 C_f = \frac{1}{(1 - \zeta)^2} \left( \frac{m+1}{2} \right) f'(0) , Re_{T_f}^2 N_i = \left( \frac{k_{of}}{k_f} + \frac{4}{3} R \right) \left( \frac{m+1}{2} \right) \phi'(0) , Sh_{T_f}^2 = \left( \frac{1}{(1 - \zeta)^2} \right) \left( \frac{m+1}{2} \right)^2 \phi(0)
\]

(18)

3. Result and discussion

In this section, the fourth/fifth order Runge Kutta method is utilised along with shooting method for the approximate solutions of equation (14) – (16) with the boundary condition in equation (17). The method is introduced by Runge Kutta around 1900 and has been used by different authors [9], [16]. The simulation is computed for the various parameters effects on temperature, \(-\theta'(0)\), along with electric field.

Fig. 2 shown the nanoparticle shapes of the nanoparticles. Table 2 displayed the thermophysical resources of the fluid and nanoparticles that were used in this work. Table 3-5 displayed the several parameters effects in the temperature profiles obtained for the dimensionless form for El = 0.0 and El = 0.5.

The effects of parameters on the magnetic field with M = 0.10, M = 0.50 and M = 0.90 is presented in Fig. 3. It is interested to report that the temperature, \(-\theta'(0)\) decreased with the extension and increased of magnetic field. This is because of the random motion of particles suspended in a fluid. Table 3 presents that the increase in the magnetic field is resulted with an increase in the temperature, \(-\theta'(0)\). As it can be seen, as the magnetic field is increasing then the concentration on the temperature, \(-\theta'(0)\) is increase when El = 0.0 and as when El = 0.5. This means temperature gradient is not influenced compared to the temperature fluctuation in the direction vertical to the magnetic field.
Fig. 4 presented the effects of parameters on the thermal radiation with $R = 0.1$, $R = 1$ and $R = 3$. It is observed that the temperature circulation for all the nanofluids increased and the rate of transfer in the heat concentration increased with the extension and increase of thermal radiation strength. The boundary of the thermal surface depth of SWCNTs – kerosene oil is dominant. This is due to the combined effects of thermal conductivity and density of the SWCNTs–nanofluid. As it can be seen, as the thermal radiation strength is increasing then the concentration on the temperature, $(-\theta'(0))$ is decreasing when $Ei = 0.0$ and as when $Ei = 0.5$. Table 4 presents that the temperature circulation for all the nanofluids increased but in contrast the rate of transfer in the heat concentration increase of thermal radiation strength. Particularly, between boundary layer at when $R = 1.0$, $R = 3.0$ and $R = 5.0$.

It is indicated from Fig. 5, which is the parameters’ effects on the heat generation ($\gamma$) with $\gamma = 0.1$, $\gamma = 0.3$ and $\gamma = 0.5$. It is observed that the temperature circulation for all the nanofluids increase but in contrast the rate of transfer in the heat concentration increased with increase of the heat generation ($\gamma$). It is well known that MHD pressure drop reduction is an important issue in the fluid mechanics. The MHD pressure drop is caused by the heat generation of a resistive electromagnetic force, which in turn increases the friction force because of the resultant flattened velocity distribution due to induced by Lorentz force as discussed in [31]. Table 5 presents that temperature circulation for all the nanofluids increase but in contrast the rate of transfer in the heat concentration increase of the heat generation ($\gamma$). Particularly, the boundary of the thermal surface depth of SWCNTs – kerosene oil is dominant. As it can be seen, as the heat generation ($\gamma$) strength is increasing then the concentration on the temperature, $(-\theta'(0))$ is decreasing when $Ei = 0.0$ and as when $Ei = 0.5$.

The temperature, $(-\theta'(0))$ of the nanofluids decrease in the presence of the magnetic field ($M = 0.1$, $M= 0.5$ and $M = 0.9$), with the increase in other nanofluid parameters, the thermal radiation ($R$) and heat generation ($\gamma$). Particularly, thermal boundary layer thickness of SWCNTs – kerosene is stronger.

**Table 2.** Thermo-physical resources of the fluid and nanoparticles.

|                  | $\sigma (\Omega^{-1} m^{-1})$ | $\rho (kg/m^3)$ | $c_p (J/kg\,K)$ | $k (W/m\,K)$ |
|------------------|-------------------------------|-----------------|-----------------|---------------|
| Kerosene         | 783                           | 2090            | 0.145           | 4.86          |
| SWCNTs-kerosene  | 2600                          | 42.5            | 6600            | 1.26          |

- Sphere ($m=3.0$)
- Cylinder ($m=6.3628$)
- Lamina ($m=16.1576$)

**Figure 2.** Nanoparticle shapes.
Table 3. Magnetic field deposition on $f^-'(0)$, $-\theta'(0)$ and $-\varphi'(0)$.

| M  | $f^-'(0)$ | $-\theta'(0)$ | $-\varphi'(0)$ | Remark |
|----|----------|---------------|----------------|--------|
| 0.1| -0.061924360.974637508 | 0.135958934 | E1 = 0.0      |
| 0.5| -0.217986560.952379683 | 0.151368698 |
| 0.9| -0.354230260.933137979 | 0.164942024 |
| 0.1| 0.206321950 | 1.014838665 | 0.109158238 |
| 0.5| 1.121600764 | 1.139776354 | 0.034226946 |
| E1 = 5.0 | 0.061924415 | 0.716012830 | 0.533825944 |
| 0.9| 2.014618856 | 1.244032672 | 0.016290443 |

Table 4. Thermal Radiation deposition on $f^-'(0)$, $-\theta'(0)$ and $-\varphi'(0)$.

| R  | $f^-'(0)$ | $-\theta'(0)$ | $-\varphi'(0)$ | Remark |
|----|----------|---------------|----------------|--------|
| 0.1| -0.061924360.974637508 | 0.135958934 | E1 = 0.0      |
| 1.0| -0.061924370.833665065 | 0.349542219 |
| E1 = 5.0 | 0.061924415 | 0.716012830 | 0.533825944 |
| 0.1| 0.206321950 | 1.014838665 | 0.109158238 |
| 1.0| 0.206321932 | 0.863339187 | 0.331765380 | E1 |
| 3.0| 0.206321895 | 0.733844123 | 0.526822455 |
Table 5. Heat generation deposition on $f'(0), -\theta'(0)$ and $-\varphi'(0)$.

| $\gamma$ | $f'(0)$  | $-\theta'(0)$ | $-\varphi'(0)$ |
|----------|-----------|---------------|---------------|
| E1 = 0.0 | 0.974637508 | 0.1359589349  |               |
| 0.1      | -0.061924366 | 0.974637508   | 0.1359589349  |
| 0.3      | -0.080758717 | 0.710446099   | 0.1653936047  |
| 0.5      | -0.061924363 | 0.396259884   | 0.1956959508  |
| E1 = 0.5 | 0.2063219507 | 1.014838665   | 0.1091582385  |
| 0.1      | 0.2063219507 | 1.014838665   | 0.1091582385  |
| 0.3      | 0.2063219526 | 0.768525605   | 0.1304137086  |
| E1 = 5.0 | 0.2063219546 | 0.396259884   | 0.1956959508  |

To confirm the present article with previous article such as [32], we compare the chemical reaction in [32], which is validate for this parameter. The result with the theoretical solution for the velocity profile is observed to be very good. Fig. 6 displayed the comparison profile.

Figure 6. Comparison of heat generation effects on temperature with [32].

4. Conclusion
The effects of various parameter namely; the thermal radiation (R) and heat generation ($\gamma$), on temperature are investigated in this work. Graphically, the results are presented and the conclusion is drawn on the various effect on the temperature with electric field.

The boundary conditions of the ODEs were solved using the same value of the governing parameter. We took several variable of the parameter as manipulated and other parameters as the constant variable, we were able to get a lot of results and reactions, which include:

- In the capacity of magnetic on the profile, the velocity decreased when the parameter M is increase, whereas at the thickness of the boundary layer for $E1 = 0.5$ is weaker as compared to $E1 = 0.0$. There is no significance difference in temperature and concentration with increasing M.
- From the profile boundary layer thickness, is indicated that the thermal radiation, heat generation and chemical is large which is show that the parameter has high effect on temperature.
• The parameter of the temperature is not increase with all the parameter when the electric field is at (E1=0.5). This show that the electric field is dominate of kerosene-SWCNT.

5. References

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