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Chemical Reaction and Particle Size Effects on Convective Heat and Mass Transfer Through a Nano Fluid

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Abstract: ***The significant research saw with nano fluid flow and heat transfer. But, there was a wide scope of research in mass transfer with nano fluids, due to Brownian motion of particles. A theoretical investigation attempted in this paper to study the chemical reaction effects during mass transfer. We studied convective heat and mass transfer of MHD nano fluid flow past inclined, oscillating permeable flat plate with heat source and suction. It found that velocity and Diffusion increases for both kinds of chemical reactions.***

Keywords: Nano - fluid, MHD, Inclined plate, Method of lines.

1. Introduction

The study of nano fluid has been attracting many researches since a few decades, due to its vital applications. The exponential growth of the study of nano fluids made the latest technology more convenient and user friendly. As the nano-fluids carriey the metallic particle the heat transfer and diffusion together is a interesting phenomenon with wide application in the field of biomedical, drug delivery etc. Sarit Kumar Das et.al (7) studied that many researches could not explain the study of diffusivity. M.I Anwar et.al (6) studied the heat and mass transfer of nano fluids over a non-linear stretching sheet for low constriction. Hyun UK Kang (2) studied the effect of Brownian motion and inertial migration of particles and concluded that the nano-particle migration to the center occurs slowly. Hence, the thermal conductivity at the walls increases. Many authors Buongiorno J (1), M. A. A. Hamad, I. Pop (5) Khan, W.A., A. Aziz (3), Kuznetsov AV, and Nield DA (4) studied the nano-fluid flow and heat transfer effects in various geometries and various effects. All the Researches used the Maxwell or Hamilton & crosser model to describe the thermal conductivity of the nano fluid. In these models there was no description about the particle diameter or layer around the particle.

Many of the researches carried out and ignored the natural phenomenon of formation of liquid like layer around nano particle because of the chemical reaction with the solvent. The formation of liquid like layer limited the contact of the metallic nano particle with the boundary. This reduced the effective heat transfer. Keeping in view all the above facts we want to study the heat and mass transfer through copper and water nano fluid with chemical reaction over a permeable, inclined, and oscillating flat plate under suction or injection.

2. Mathematical Formulation

Consider the unsteady three dimensional free convection flow of a nano-fluid past a vertical permeable semi-infinite plate in the presence of an applied magnetic field with constant heat source and radiation. We consider a Cartesian coordinate system $(\bar{x},\bar{y},\bar{z})$ .The flow assumes to be in the $\bar{x}$ direction, which takes along the plate, and $\bar{z}$ - axis is normal to the plate. We assume that the plate has an oscillatory movement on time $\bar{t}$ and frequency $\bar{n}$ with the velocity u(0,t),which gives $u(0,t) = U_0 (1 + \varepsilon \cos(nt))$, where ε is a small constant parameter ($\varepsilon << 1$) and U_0 is the characteristic velocity. We consider that initially ($t < 0$) the fluid as well as the plate is at rest. A uniform external magnetic field B_0 takes to be acting along the $\bar{z}$-axis. We consider the case of a short circuit problem in which the applied electric field E = 0, and also assume that the induced magnetic field is small compared to the external magnetic field B_0. The surface temperature assumes to have the constant value T_w while the ambient temperature is the constant value T_∞, where $T_w > T_\infty$. The conservation equation of current density $\nabla . J = 0$ gives J_z = constant. Since, the plate is electrically non-conducting, this constant is zero. It assumes that the plate is infinite in some extent. Hence, all physical quantities do not depend on $\bar{x}$ and $\bar{y}$ but depend only on $\bar{z}$ and $\bar{t}$,

i.e $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

It assumes that the regular fluid and the suspended nano-particles are in thermal equilibrium, no slip occurs between them. Under Bossinesq and boundary layer approximations, the boundar layer equations governing the flow and temperature are:

$$\frac{\partial w}{\partial z} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} = \frac{1}{\rho_{nf}}\left[\mu_{nf}\frac{\partial^2 u}{\partial z^2} + (\rho\beta_T)_{nf} g(T-T_\infty)\cos\gamma + (\rho\beta_c)_{nf} g(c-c_\infty)\cos\gamma\right] \tag{2}$$

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = \alpha_{nf}\frac{\partial^2 T}{\partial z^2} - \frac{Q}{(\rho c_p)_{nf}}(T-T_\infty) \tag{3}$$

$$\frac{\partial c}{\partial t} + w\frac{\partial c}{\partial z} = D_{nf}\frac{\partial^2 c}{\partial z^2} + k_l(c - c_\infty) \quad (4)$$

The appropriate initial and boundary conditions for the problem is given by

$$\left.\begin{array}{l} u(z,t) = 0, T = T_\infty, c = c_\infty \ \ for\ t < 0\ \forall\ z \\ u(0,t) = U_0\left[1 + \frac{\varepsilon}{2}(e^{int} + e^{-int})\right], T(0,t) = T_w,\ c(0,t) = c_w \\ u(\infty,t) \to 0, T(\infty,t) \to T_\infty,\ c(\infty,t) \to c_\infty,\ \varepsilon << 1 \end{array}\right\} \ t \geq 0 \quad (5)$$

Thermo-Physical properties are related as follows:

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_s,\ \alpha_{nf} = \frac{k_{nf}}{(\rho c_p)_{nf}}$$

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_f + \phi(\rho c_p)_s$$

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_f + \phi(\rho c_p)_s$$

$$k_{nf} = k_f(1-\phi) + \beta_1 k_p \phi + c_1 \frac{d_f}{d_p} k_p \,\mathrm{Re}^2 d_p\, pr\, \phi$$

$$\frac{\mu_{nf}}{\mu_f} = 1 + 2.5\phi + 4.5\left[\frac{1}{\frac{h}{d_p}\left(2+\frac{h}{d_p}\right)\left(1+\frac{h}{d_p}\right)^2}\right] \quad (6)$$

$\beta_1 = 0.01$ is a constant for considering the kapitza resistance per unit area

$c_1 = 18\times10^6$ is proportionality constant

$$\mathrm{Re}\, d_p = \frac{d_p}{\gamma_f}\frac{\kappa T}{3\pi\mu_f d_p l_f} = \frac{1.381\times10^{23} T}{\gamma_f 3\pi\mu_f (0.738)}$$

$d_f = 0.384$ nm for water

Pr = Prandtl number = $\frac{\gamma_f}{\alpha_f}$

l_f = Mean free path = 0.738

k = Boltzmann constant, T = 300 k

We consider the solution of Esq. (1) as w = - w_0 (7)

Where the constant w_0 represents the normal velocity at the plate which is positive for suction (w_0>0) and negative for blowing or injection (w_0<0).Thus, we introduce the following dimensionless variables:

$$z = \left(\frac{\psi_f}{U_0}\right)Z,\ t = \left(\frac{\psi_f}{U_0^2}\right)t^*,\ n = \left(\frac{U_0^2}{\psi_f}\right)\eta,$$

$$u = UU_0,\ \theta = \frac{T - T_\infty}{T_w - T_\infty},\ c = \frac{c - c_\infty}{c_w - c_\infty}$$

Using equations 5, 6, 7 the Equations 2, 3 & 4 can be Written in the following dimensionless form:

$$\left[1-\phi+\phi\left(\frac{\rho_s}{\rho_f}\right)\right]\left(\frac{\partial U}{\partial\tau} - S\frac{\partial U}{\partial Z}\right) = 1 + 2.5\phi + 4.5\left[\frac{1}{\frac{h}{d_p}\left(2+\frac{h}{d_p}\right)\left(1+\frac{h}{d_p}\right)^2}\right]\frac{\partial^2 U}{\partial Z^2}$$

$$+\left[1-\phi+\phi\frac{(\rho\beta_T)_s}{(\rho\beta_T)_f}\right]\theta Ca_\gamma + \left[1-\phi+\phi\frac{(\rho\beta_c)_s}{(\rho\beta_c)_f}\right]\frac{G_c}{G_r}\, C\, Ca_\gamma$$

$$\left[1-\phi+\phi\frac{(\rho c_p)_s}{(\rho c_p)_f}\right]\left(\frac{\partial\theta}{\partial\tau} - S\frac{\partial\theta}{\partial Z}\right) =$$

$$\frac{1}{p_r}\left[\left(1-\phi+0.01\phi\frac{k_p}{k_f} + \frac{k_p}{k_f^2}\phi\frac{\rho_f^2 c_{pf}}{d_p\mu_f^3}28632.9991\times10^{-52}\right)\frac{\partial^2\theta}{\partial Z^2}\right]$$

$$-\frac{1}{p_r}Q_H\theta$$

$$\left(\frac{\partial c}{\partial\tau} - S\frac{\partial c}{\partial Z}\right) = \frac{1}{Sc}\frac{\partial^2 c}{\partial Z^2} + K\,C$$

Where the corresponding boundary conditions (5) can be written in the dimensionless form as:

$$\left.\begin{array}{l} U(z,t) = 0, \theta(z,t) = 0, C(z,t) = 0 \ \ for\ t < 0\ \forall\ z \\ U(0,t) = U_0\left[1 + \frac{\varepsilon}{2}(e^{int} + e^{-int})\right], \theta(0,t) = 1, C(0,t) = 1 \\ U(\infty,t) \to 0,\ \theta(\infty,t) \to 0, C(\infty,t) \to 0 \end{array}\right\} \forall\ t \geq 0$$

Here p_r is the Prandtl number, S is the suction (S>0) or injection (S<0) parameter, Q_H is the heat source parameter, Sc is the Schimdth number, K is the chemical Reaction parameter, Gr is the Grashof number, Gc is the Molecular Grashof number, which is defined as:

$$p_r = \frac{\psi_f}{\alpha_f},\ S = \frac{w_o}{U_0},\ Q_H = \frac{Q\psi_f^2}{k_f U_0^2},$$

$$Sc = \frac{\psi_f}{D_{nf}},\ K = \frac{k_l\psi_f}{U_0^2}$$

$$\frac{Gc}{Gr} = \left(\frac{\beta_{cf} g(c_w - c_\infty)\gamma_f}{\beta_{Tf} g(T_w - T_\infty)\gamma_f}\right)$$

Where the velocity characteristic U_0 is defined as

$$U_0 = \left[g\beta_f(T_w - T_\infty)\psi_f\right]^{1/3}$$

The local Nusselt number Nu in dimension less form:

$$Nu = -\frac{k_{nf}}{k_f}\theta'(0)$$

3. Results and Discussions

The governing equation solves by using Method of lines with the help of Mathematical package and Z is limited to 6. The variations of velocity U, temperature θ and diffusion C are

graphically exhibited. By keeping Pr = 6.2, nt = π/2 and ε = 0.02. The effects of various parameters are as follows**:**

The velocity increases with increase in volume fraction (ϕ) of the nano-fluid. It indicates the nano particle density dominates the motion of the solute more. It is exhibited in Fig. 1.The variation of U with liquid like layer thickness (h) exhibits in Fig.2. The flow resists with increase in h. As the thickness increases the flow of the nano-fluid is very much decreasing. From Fig. 3. It is observed that the flow increases with particle size (d_p). The friction **is** among the liquid and the metal particles enhance the velocity. From Fig.4. The velocity decreases with increase in the inclination angle (γ) of the plate. From Fig.5. The velocity decreases with increase in the heat source (Q_H). There is no significant influence on the flow field by the moderate heat source. From Fig.6. The increase in kinematic viscosity/decrease in diffusivity (**Sc**) decreases the velocity. From Fig. 7. The velocity increases from generative (K<0) to destructive (K>0) chemical reactions and found moderate for no reaction. From Fig. 8. It observes that the increase in solid particles (ϕ) increases the temperature. Fig. 9 exhibits the variation of temperature with size of the solid particle (d_p). The temperature increases with increase in size of the particle. Fig. 10 is temperature profile varying with heat source parameter (Q_H). It finds that the temperature decreases with increase in heat source. The diffusivity decreases with increase in kinematic viscosity (**Sc**) from Fig. 11.The diffusivity increases with chemical reaction (K) changes from generative to destructive from Fig.12.

4. Nussellt Number

The variation of rate of heat transfer coefficient for various volume fractions, size of the particle and heat source displays in Table – 1. The rate of heat transfer increases with increase in heat source for all volume fractions of the solid particles. But, the rate of heat transfer is almost constant for low volume fractions for various sizes of the particle**,** where as a significant enhancement of rate of heat transfer observes for increase in size of the particle for higher volume fractions.

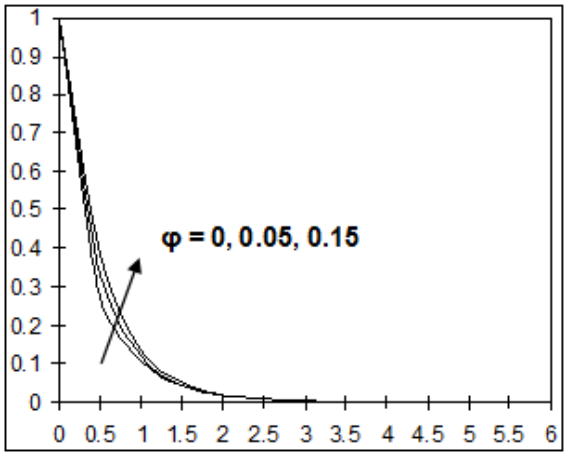


Figure 1: Variation of U with ϕ

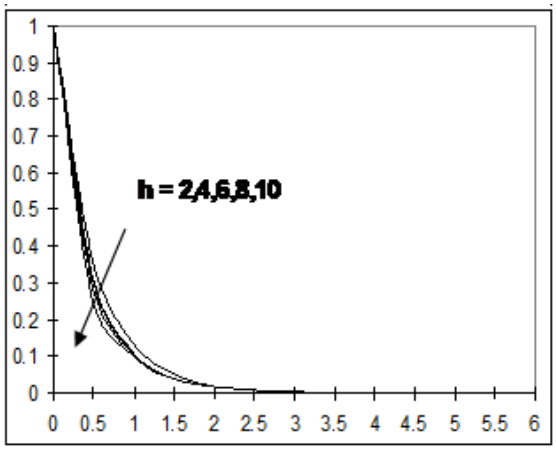


Figure 2: Variation of U with h

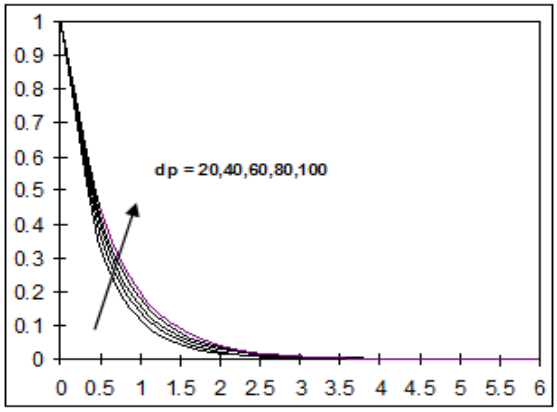


Figure 3: Variation of U with d_p

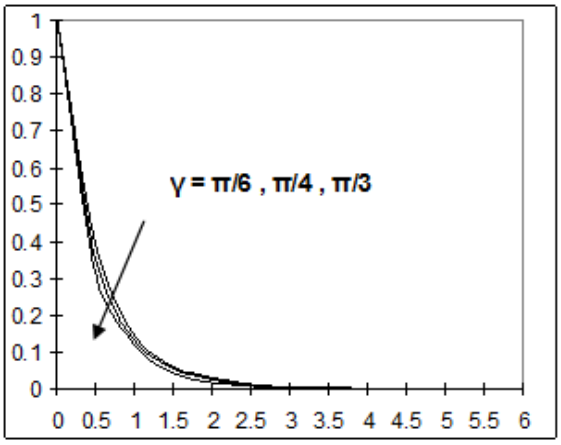


Figure 4: Variation of U with γ

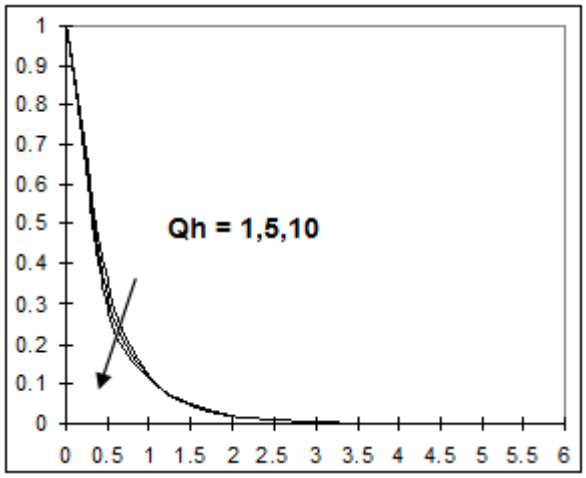


Figure 5: Variation of U with Q_H

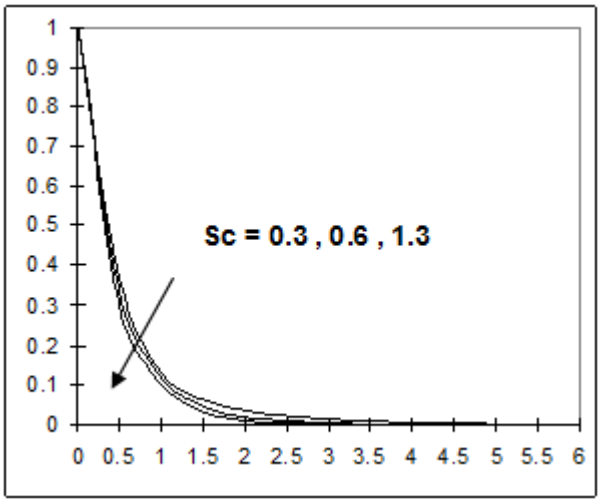


Figure 6: Variation of U with Sc

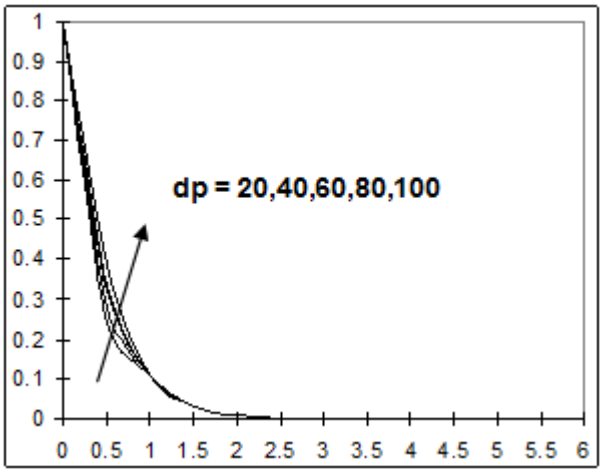


Figure 9: Variation of θ with d_p

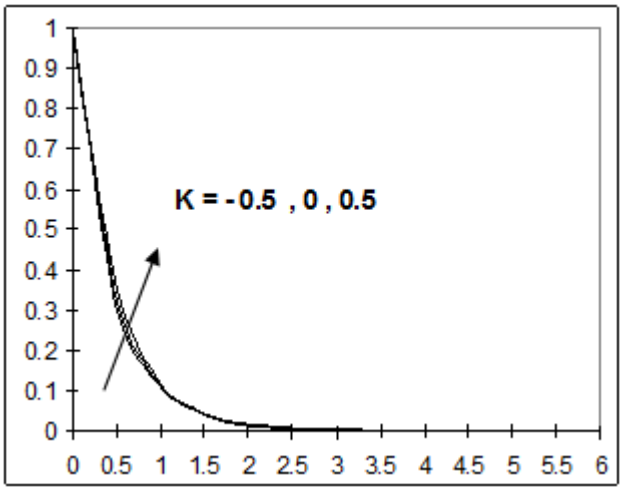


Figure 7: Variation of U with K

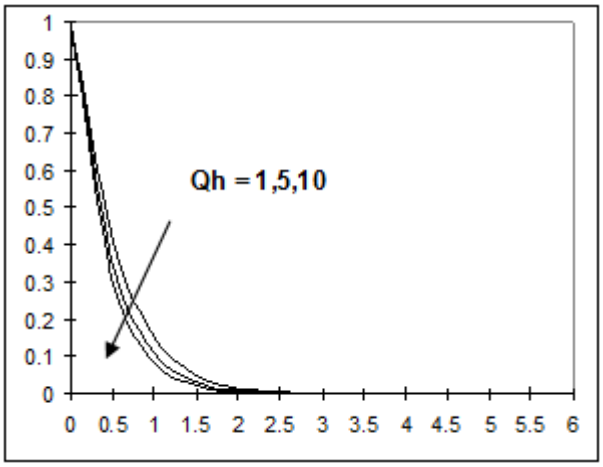


Figure 10: Variation of θ with Q_H

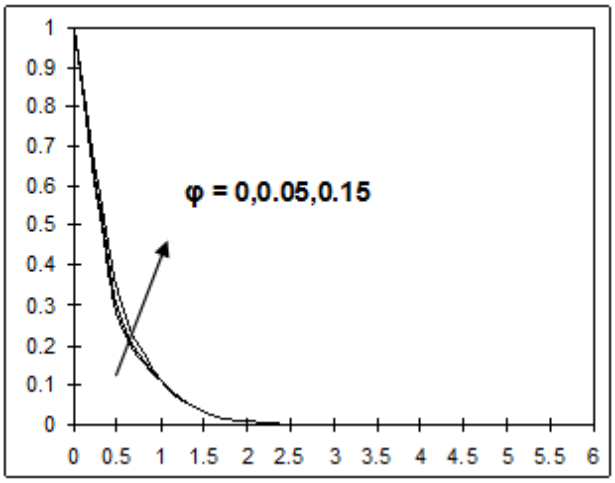


Figure.8: Variation of θ with ϕ

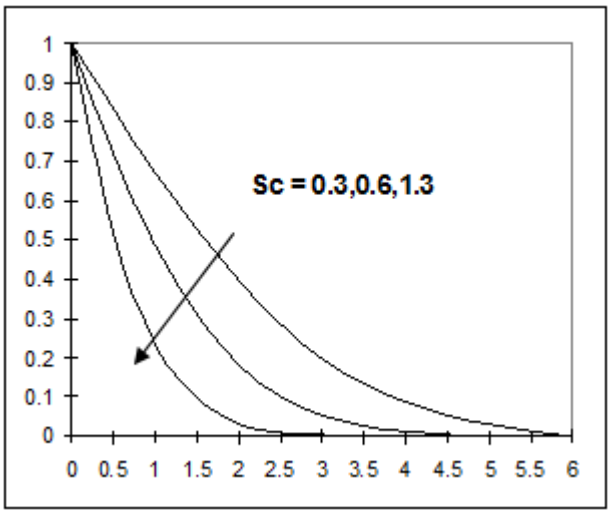


Figure 11: Variation of C with Sc

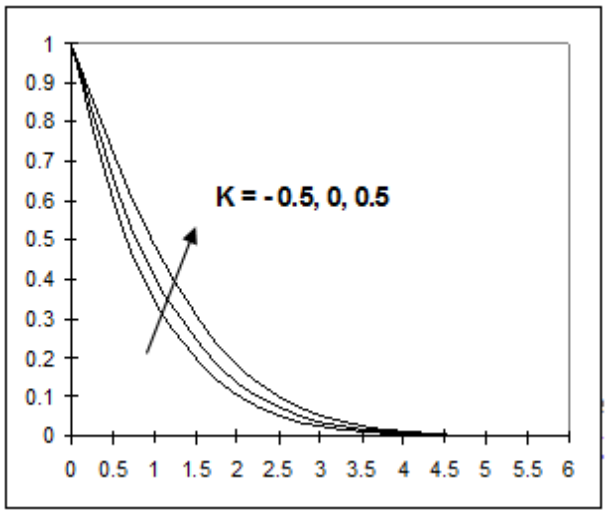


Figure 12: Variation of C with K

Table-1: Nusselt Number

S=1, $\gamma = \pi/3$, $Sc = 0.6$, $k = 0.5$

ϕ	$Q_H = 5$; $d_p = 20$	$Q_H = 5$; $d_p = 40$	$Q_H = 5$; $d_p = 100$	$Q_H = 1$; $d_p = 20$	$Q_H = 10$; $d_p = 20$
0.05	1.99986	1.99986	1.99984	1.56649	2.45631
0.15	2.64386	2.64438	2.64439	2.05106	3.2664
ϕ	$Q_H = 5$; $d_p = 20$	$Q_H = 5$; $d_p = 40$	$Q_H = 5$; $d_p = 100$	$Q_H = 1$; $d_p = 20$	$Q_H = 10$; $d_p = 20$
0.05	1.99986	1.99986	1.99984	1.56649	2.45631
0.15	2.64386	2.64438	2.64439	2.05106	3.2664

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