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Free convection boundary layer flow mass transfer with chemical reaction over a porous inclined plate in presence of magnetic field

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Abstract— The present study is an investigation of mass transfer with chemically reactive solute distribution in steady MHD boundary layer free convection flow of an incompressible electrically conducting fluid over a porous inclined plate under the influence of an applied uniform magnetic field. Using suitable similarity transformations the governing fundamental boundary layer equations are approximated by a system of non-linear similar ordinary differential equations for momentum and concentration equations which are then solved numerically by Runge- Kutta fourth-fifth order integration scheme along with the shooting technique. The numerical results concerned with the velocity and concentration profiles effects of various parameters on the flow fields are investigated and presented graphically. The results presented graphically illustrate that velocity field decreases due to increase of Magnetic parameter, angle of inclination and other parameters increase the velocity of the fluid flow. Concentration profiles increases for increasing the values of order of reaction, Solutal Grashof number decreases for chemical reaction, magnetic parameter, angle of inclination, Suction/injection and Schmidt number. In the case of suction/injection the velocity field is increasing within the certain values of η and then decreases. Also the skin friction coefficient and the local Sherwood number are presented in Table1.

Index Terms— Chemical Reaction, Convection, Inclined Plate, Injection, Magnetic field, Mass transfer, Porous, Suction.

1 Introduction

The study of MHD flow problems has significant applications in industrial manufacturing processes such as Magneto-hydrodynamics power generator, cooling of Nuclear reactors, boundary layer control in aerodynamics, plasma studies and petroleum industries. The study of effects of porous boundaries on heat and mass transfer is important because of its many engineering applications in the field of chemical and geophysical sciences. Permeable porous plates are used in the filtration processes and also for a heated body to keep its temperature constant and to make the heat in solution of the surface more effective. Anjalidavi and Kandasamy [1] analyzed the effects of chemical reaction, heat and mass transfer on laminar flow along a semi infinite horizontal plate. Mukhopadhyay and Layek [2] studied the radiation effects on forced convective flow and heat transfer over a porous plate in a porous medium. Recently, Chamkha et al. [3] discussed the chemical reaction effect on unsteady MHD free convective flow of micropolar fluid in a vertical porous plate. Anjalidavi and Kandasamy [4] analyzed the effects of chemical reaction on the flow past a semi infinite plate in presence of a magnetic field. Damseh et al. [5] obtained the similarity solution of forced convection flow with magnetic field and thermal radiation effects. Recently, Sharma and Singh [6] studied the MHD free convective flow over an inclined porous plate with variable thermal conductivity. Krishnendu Bhattacharyya et al. [7] obtained the Similarity solution of MHD boundary layer flow with diffusion and chemical reaction over a porous flat plate with suction/blowing. In addition, some very important investigations in this direction were made in the articles [8–10]. In the present analysis we have studied mass transfer with chemically reactive solute distribution in steady MHD boundary layer free convection flow of an incompressible electrically conducting fluid over a porous inclined plate under the influence of an applied uniform magnetic field. Adapting suitable similarity transformations the governing fundamental boundary layer equations are approximated by a system of non-linear similar ordinary differential equations for momentum and concentration equations which are then solved numerically by Runge- Kutta fourth-fifth order integration scheme along with the shooting technique. The numerical results concerned with the primary velocity and concentration profiles effects of various parameters on the flow fields are investigated and presented graphically. The results presented graphically illustrate that velocity field decreases due to increase of Magnetic parameter, angle of inclination and other parameters increase the velocity of the fluid flow. Concentration profiles increases for increasing the values of order of reaction, Solutal Grashof number decreases for chemical reaction, magnetic parameter, angle of inclination, Suction/injection and Schmidt number. In the case of suction/injection the velocity field is increasing within the certain values of η and then decreases. Also the skin friction coefficient and the local Sherwood number are presented in Table1.

2 Formulation of the Problem and Similarity Analysis

Let us consider steady two dimensional MHD free convection mass transfer in an incompressible electrically conducting fluid flow over a porous inclined plate under the influence of an applied uniform magnetic field with chemical reaction. The flow is subjected to a transverse magnetic field of strength B_0 which is assumed to be applied in the positive y –direction normal to the surface. The pressure gradient, body force, viscous dissipation and joule heating effects are neglected compared with the effects of internal heat source/sink. Under the

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above assumptions and usual boundary layer approximation, the dimensional governing equations of continuity, momentum and concentration under the influence of externally imposed magnetic field are:

Equation of continuity: $\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0$ (1)

Momentum equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta(C-C_\infty)\cos\gamma-\frac{\sigma B_0^2}{\rho}u \quad (2)$$

Concentration equation:

$$u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=D\frac{\partial^2 c}{\partial y^2}-R(C-C_\infty)^n \quad (3)$$

Boundary conditions are:

$u=0, v=V_w, C=C_w$ at $y=0$, $u\to 0, C\to C_\infty$ as $y\to\infty$

To convert the governing equations into a set of similarity equations, we introduce the following similarity transformation:

$$\eta=y\sqrt{\frac{A}{\nu x}},\ \psi=\sqrt{\nu x A}f(\eta),\ \varphi(\eta)=\frac{C-C_\infty}{C_w-C_\infty},\ u=\frac{\partial\psi}{\partial y},\ v=-\frac{\partial\psi}{\partial x}$$

From the above transformations, the non-dimensional, nonlinear and coupled ordinary differential equations are obtained as

$$f'''+\frac{1}{2}ff''-Mf'+\varphi G_m\cos\gamma=0 \quad (4)$$

$$\varphi''+\frac{1}{2}S_c f\varphi'-S_c R^*\varphi^n=0 \quad (5)$$

The transform boundary conditions:

$f=-f_w,\ f'=0,\ \varphi=1$ at $\eta=0$ and
$f'\to 0,\ \varphi\to 0$ as $\eta\to\infty$

3 RESULTS AND DISCUSSION

The system of ordinary differential equation (4) and (5) subject to the boundary conditions is solved numerically by Runge-Kutta fourth-fifth order integration scheme along with the shooting technique. First of all, higher order non-linear differential equations (4) and (5) are converted into simultaneous linear differential equations of first order and they are further transformed into initial value problem. Numerical calculation for distribution of the velocity and concentration profiles across the boundary layer for different values of the parameters is carried out. Fig.1-Fig.7 show the velocities obtained by the numerical simulations for various values of entering parameters. Fig.1 clearly demonstrates that the velocity starts from minimum value at the surface and increases till it attains the peak value and then starts decreasing until it reaches to the minimum value at the end of the boundary layer for all the values M. It is interesting to note that the effect of magnetic field is more prominent at the point of peak value, because the presence of M in a electrically conducting fluid introduce a force like Lorentz force which acts against the flow if the magnetic field is applied in the normal direction as in the present problem. As a result velocity profile is decreased. Similar result arises for the angle of inclination which shown in Fig.2 Reverse trend has seen in Fig.3, Fig.4, Fig.5 and Fig.6 with increase of order of reaction, Solutal grashof number, reaction parameter and Schmidt number. As expected, it is observed that an increase in Gm leads to increase in the values of velocity due to enhancement in mass buoyancy force. Here the positive values of Gm corresponding to cooling of the surface. From Fig.7 it is observed that the velocity is increased near the plate and decrease far away from the plate for both suction and injection. Fig.8-Fig.14 shows the concentration profiles obtained by the numerical simulation for various values of entering non-dimensional parameters. From Fig.8, Fig.9, Fig.10 and Fig.11 a negligible effect is observed for entering parameters on concentration. From Fig.12-Fig14 it is observed that the concentration is decreased for increasing values of entering parameters. As the smaller values of Schmidt number are equivalent the chemical molecular diffusivity, hence the concentration decreases which shown in Fig.13. Table 1 exhibit the behavior of $f''(0)$ and $-\varphi'(0)$, for various values of magnetic parameter, angle of inclination, order of reaction, Grashof number, reaction parameter and Schmidt number. From Table- 1, it is observed that $f''(0)$ is decreased for various values of M and γ and increased for increasing values of n, Gm , R* and Sc. Also we see that $-\varphi'(0)$, is increased with the increase of n, and Gm and decreased for M, γ, R* and Sc.

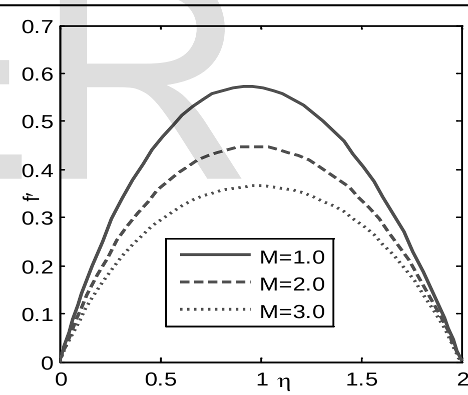

Fig.1.Velocity Profile for various values of M and R* =1.0, n=2.0, γ =60o,Gm=3.0,Sc=0.22,fw=1.

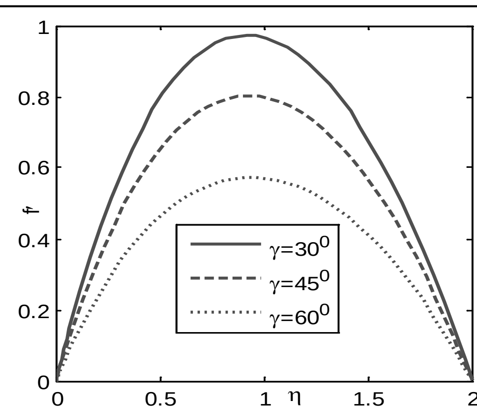

Fig.2.Velocity Profile for various values of γ and R* =1.0, n=2.0, M=1.0,Gm=3.0,Sc=0.22,fw=1.

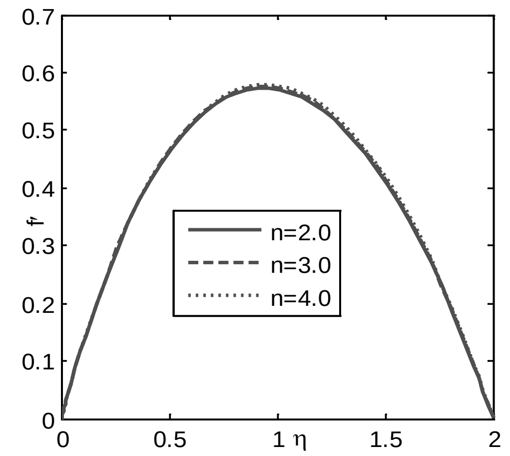

Fig.3.Velocity Profile for various values of n and R* =1.0, M=1.0, γ =60o,Gm=3.0,Sc=0.22,fw=1.

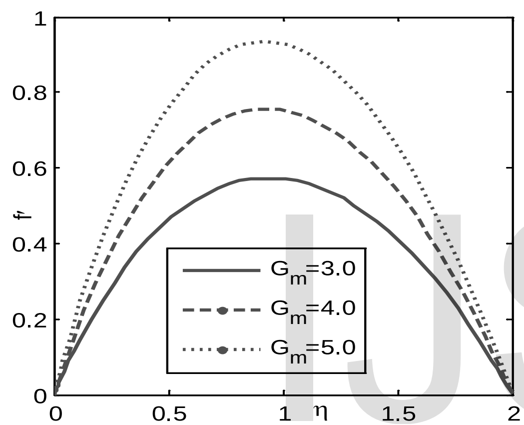

Fig.4.Velocity Profile for various values of G_m and R* =1.0, M=1.0, γ =60o,n=2.0,Sc=0.22,fw=1.

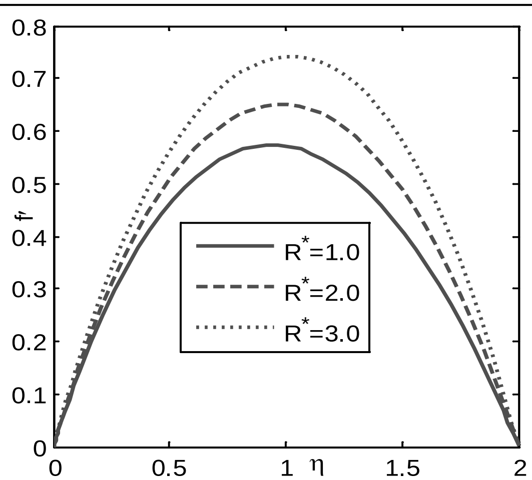

Fig.5.Velocity Profile for various values of R^* and M =1.0, n=2.0, γ =60o,Gm=3.0,Sc=0.22,fw=1.

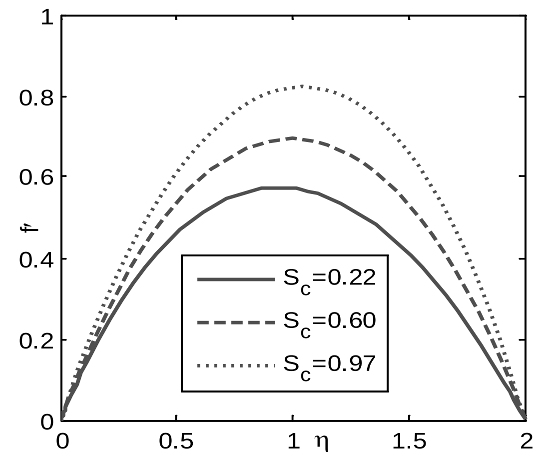

Fig.6.Velocity Profile for various values of S_c and R* =1.0, M=1.0, γ =60o,Gm=3.0,n=2.0,fw=1.

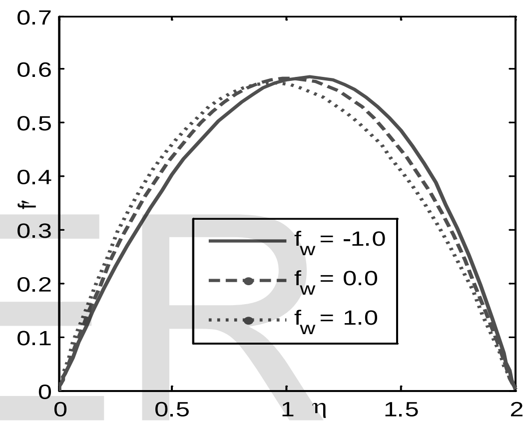

Fig.7.Velocity Profile for various values of f_w and R* =1.0, M=1.0, γ =60o,Gm=3.0,n=2.0,S_c=0.22.

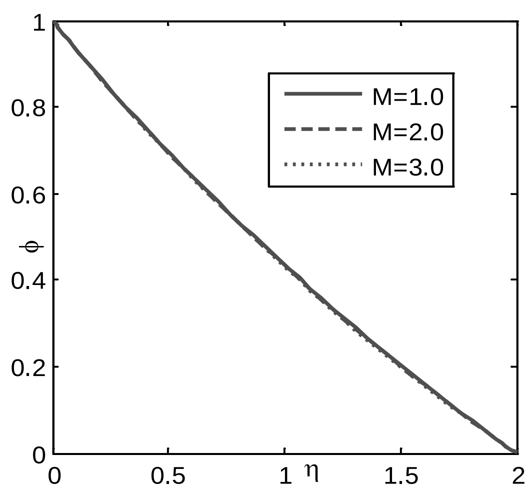

Fig.8.Concentration Profile for various values of M and R* =1.0, n=2.0, γ =60o,Gm=3.0,Sc=0.22,fw=1.

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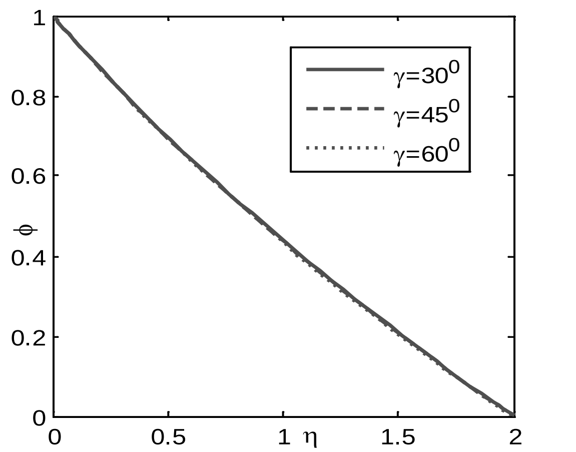

Fig.9.Concentration Profile for various values of γ and R* =1.0, n=2.0, M=1.0,Gm=3.0,Sc=0.22,fw=1.

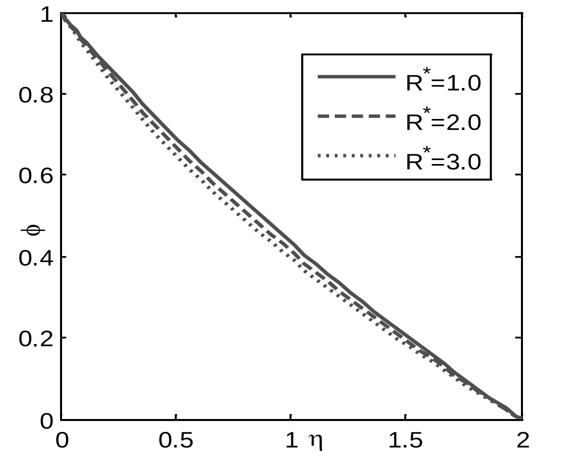

Fig.12.Concentration Profile for various values of R^* and M =1.0, n=2.0, γ =60o,Gm=3.0,Sc=0.22,fw=1.

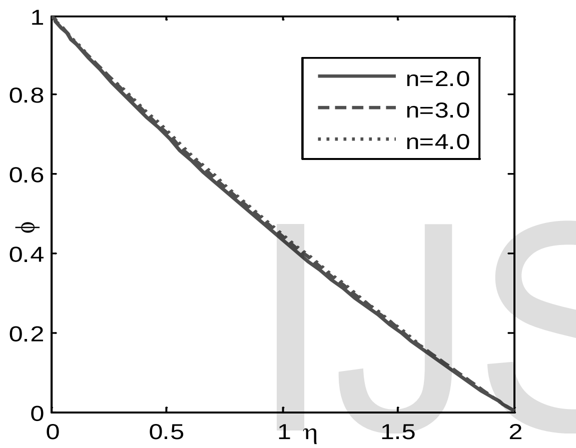

Fig.10.Concentration Profile for various values of n and R* =1.0, M=1.0, γ =60o,Gm=3.0,Sc=0.22,fw=1.

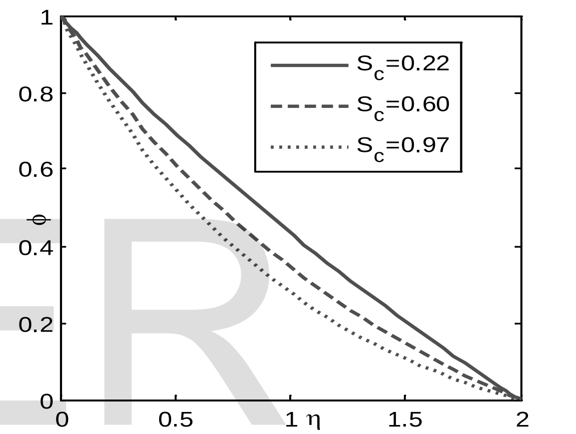

Fig.13.Concentration Profile for various values of S_c and R* =1.0, M=1.0, γ =60o,Gm=3.0,n=2.0,fw=1.

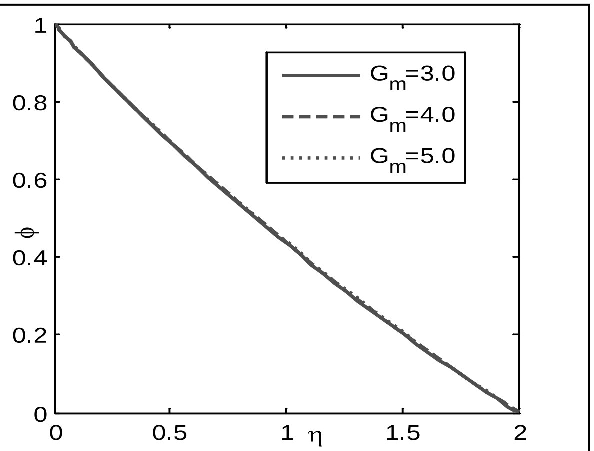

Fig.11.Concentration Profile for various values of G_m and R* =1.0, M=1.0, γ =60o,n=2.0,Sc=0.22,fw=1.

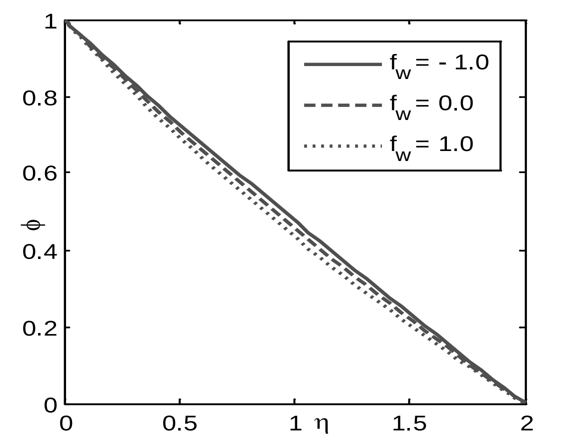

Fig.14.Concentration Profile for various values of f_w and R* =1.0, M=1.0, γ =60o,Gm=3.0,n=2.0,S_c=0.22.

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4 Conclution

Number The present study is an investigation of mass transfer with chemically reactive solute distribution in steady MHD boundary layer free convection flow of an incompressible electrically conducting fluid over a porous inclined plate under the influence of an applied uniform magnetic field. Using suitable similarity transformations the governing fundamental boundary layer equations are approximated by a system of non-linear similar ordinary differential equations for momentum and concentration equations which are then solved numerically by Runge- Kutta fourth-fifth order integration scheme along with the shooting technique. The numerical results concerned with the velocity and concentration profiles effects of various parameters on the flow fields are investigated and presented graphically. The following remarks can be concluded from the analysis:

- Due to chemical reaction the concentration boundary layer thickness decreases with the increasing Schmidt number which is similar for the flat plate [7].
- For increasing the order of reaction causes to enhance the concentration and reverse trend arises for reaction parameter.
- For the increase of suction the solute boundary layer thicknesses increases, on the other hand, boundary layer thickness becomes thinner for the injection. Similar result arises for momentum boundary layer thickness $(0 \le \eta \le 1)$.
- For applying external magnetic field the momentum boundary layer thickness decreases which is expected.

Nomenclature

MHD	Magnetohydrodynamics
g	Gravitational acceleration
f'	Velocity Profile
M	Magnetic parameter, $M = \frac{x\,\sigma B_0^2}{\rho A}$
v	Kinematic viscosity
η	Similarity variable
β	Coefficient of expansion with concentration
ρ	Density
σ	Fluid electrical conductivity
u	Velocity component in x-direction
v	Velocity component in y-direction
D	Thermal molecular diffusivity
f_w	Dimensionless suction velocity
C_∞	Concentration of the fluid outside the boundary layer
G_m	Local solutal Grashof number $G_m = \frac{g\beta(C_w - C_\infty)x}{A^2}$
S_c	Schmidt number, $S_c = \frac{v}{D}$
R*	Reaction rate parameter, $R^* = \frac{LR_0(C_w - C_\infty)^{n-1}}{A}$
R	Reaction rate, $R = \frac{LR_0}{x}$
B_0	Constant magnetic field intensity
A	Constant velocity
v_w	Suction velocity
u_∞	Velocity outside the boundary layer
γ	Angle of inclination
L	Reference length
R0	Constant
n	Order of reaction
Subscript	
w	Quantities at wall
∞	Quantities at the free stream

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Table-1: The skin friction coefficient $f''(0)$ at the wall and the local Sherwood number, $-\varphi'(0)$ for various values of M, γ, n, Gm , R* , Sc and taking fw=1.0

M	γ	n	Gm	R*	Sc	$f''(0)$	$-\varphi'(0)$
1.0	600	2	3.0	1	0.22	1.390613	0.672619
2.0	600	2	3.0	1	0.22	1.130079	0.674522
3.0	600	2	3.0	1	0.22	0.960558	0.676675
1.0	300	2	3.0	1	0.22	2.400925	0.667446
1.0	450	2	3.0	1	0.22	1.966003	0.669599
1.0	600	2	3.0	1	0.22	1.390613	0.672619
1.0	600	2	3.0	1	0.22	1.390613	0.672619
1.0	600	3	3.0	1	0.22	1.393835	0.651754
1.0	600	4	3.0	1	0.22	1.397629	0.638207
1.0	600	2	3.0	1	0.22	1.390613	0.672619
1.0	600	2	4.0	1	0.22	1.847695	0.670305
1.0	600	2	5.0	1	0.22	2.3015191	0.667965
1.0	600	2	3.0	1	0.22	1.390613	0.672619
1.0	600	2	3.0	2	0.22	1.492588	0.762932
1.0	600	2	3.0	3	0.22	1.610314	0.845964
1.0	600	2	3.0	1	0.22	1.390613	0.672619
1.0	600	2	3.0	1	0.60	1.550241	0.945107
1.0	600	2	3.0	1	0.97	1.714245	1.190784

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