Universität Bremen

ITEM

Modeling and simulation of Microfluidics systems

By :
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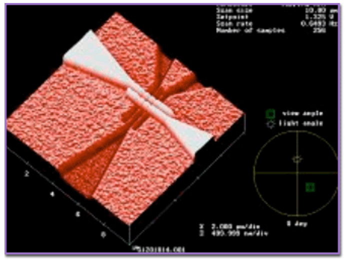
Introduction to MEMS

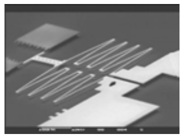
Micro Elector Mechanical Systems

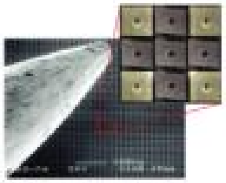
Do you use MEMS ???

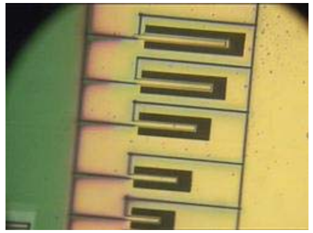
flash memory, cd/dvd drives …

airbag sensors & actuators



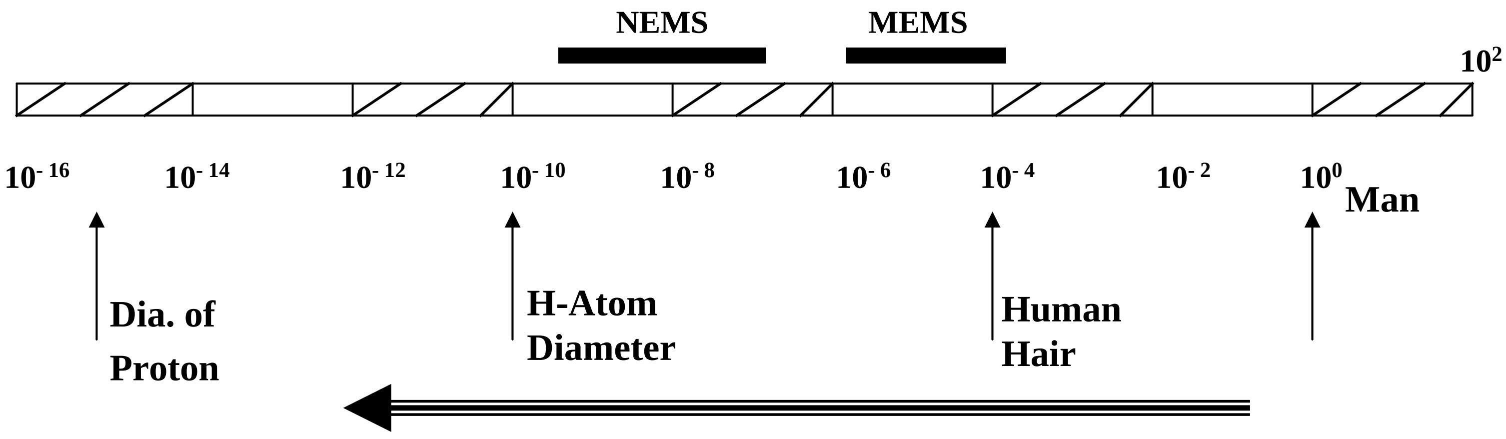






micromirrors, projectors

Scaling Issues



- the nature of phenomena changes with reducing sizes. e.g., gravitational force, surface tension effect, magnetic force, etc.

What is different between fluid flow in a normal scale and in a microchannel

In a normal size we can assume that near the wall (at wall-fluid interface), velocity of fluid is zero, but due to the small size in microchannel, this assumption is not true. We can characterize microfluidic with Knudsen number (Kn).

$Kn = \frac{\lambda}{D_h}$, $D_h = 2W$ and λ is the mean free path of fluid

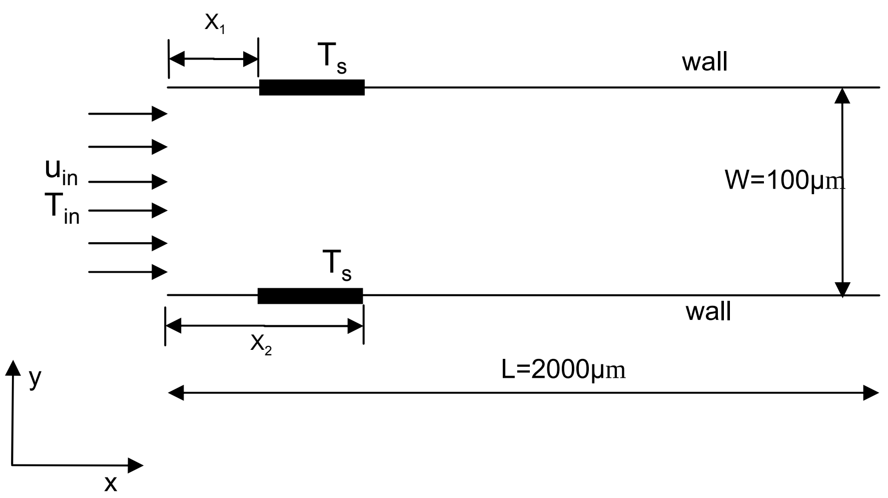
$Kn \leq 0.001$ continuum flow regime, $0.001 < Kn \leq 0.1$ slip flow regime

$0.1 < Kn \leq 10$ transition flow regime , $Kn > 10$ free molecular flow regime

To reach this assumption, researchers suggest the following expression:

$$U = \left(\frac{2-\sigma_V}{\sigma_V}\right) Kn \frac{\partial U}{\partial y} + \frac{3}{2\pi} \frac{(\gamma - 1)}{\gamma} \frac{Kn^2 \,\mathrm{Re}}{Ec} \frac{\partial \theta}{\partial X} \qquad U = Kn \frac{\partial U}{\partial n}$$

$$\theta - \theta_{wall} = \left(\frac{2-\sigma_T}{\sigma_T}\right)\left(\frac{2\gamma}{\gamma+1}\right) \frac{Kn}{\mathrm{Pr}} \frac{\partial \theta}{\partial y} \qquad \theta - \theta_{wall} = \frac{Kn}{\beta} \frac{\partial \theta}{\partial n}$$



Boundary condition:

Inlet (x=0): u=u_{in} , v=0 and T=T_{in}

Outlet (x=L): $\frac{\partial \Phi}{\partial x} = 0$

where Φ =u, v, T

but p=0

At wall (y=0, y=W):

u=v=0, $x_1 \le x \le x_2: \quad T = T_s$

$0 \le x < x_1 \quad and \quad x_2 < x \le L: \quad \frac{\partial T}{\partial y} = 0$

also: near the wall $U = Kn \frac{\partial U}{\partial n}$

$$\theta - \theta_{wall} = \frac{Kn}{\beta} \frac{\partial \theta}{\partial n}$$

$$\beta = \left(\frac{\gamma+1}{2\gamma}\right) Pr$$

Governing equations

Continuity: $$\frac{\partial u_j}{\partial x_j} = 0$$

Momentum: $$\frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial}{\partial x_j}\left(\mu(\frac{\partial u_i}{\partial x_j})\right) - \frac{\partial p}{\partial x_i}$$

Energy: $$\frac{\partial}{\partial x_i}\left(\rho c_p u_i T\right) = k \frac{\partial}{\partial x_i}\left(\frac{\partial T}{\partial x_i}\right)$$

Non-dimensional equations

$$X_i = \frac{x_i}{D_h} \quad , \quad U_i = \frac{u_i}{u_{in}} \quad , \quad \theta = \frac{T - T_{in}}{T_{wall} - T_{in}} \quad , \quad P = \frac{p}{\rho u_{in}^2}$$

$$D_h = \frac{4A}{S} \quad , \quad D_h = \frac{4WH}{2(W + H)}$$

and also H >> W So: $D_h = 2W$

$$\Pr = \frac{\mu c_p}{k} \quad , \quad \mathrm{Re} = \frac{\rho u_{in} D_h}{\mu} \quad , \quad Pe = \mathrm{Re}\,\Pr$$

Continuity:

$$\frac{\partial U_j}{\partial X_j} = 0$$

Momentum:

$$\frac{\partial}{\partial X_j}(U_i U_j) = \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 U_i}{\partial X_j^2}\right) - \frac{\partial P}{\partial X_i}$$

Energy:

$$\frac{\partial}{\partial X_i}(U_i \theta) = \frac{1}{Pe}\frac{\partial^2 \theta}{\partial X_i}$$

Discretization Methods

- *Finite element method*
- *Finite difference method*
- *Finite volume method (Control volume technique)*
- *Other methods…*

Finite volume technique

- *First order upwind scheme*
- *Second order upwind scheme*
- *QUICK (Quadratic Upwind Interpolation)*
- *Power law scheme*
- …

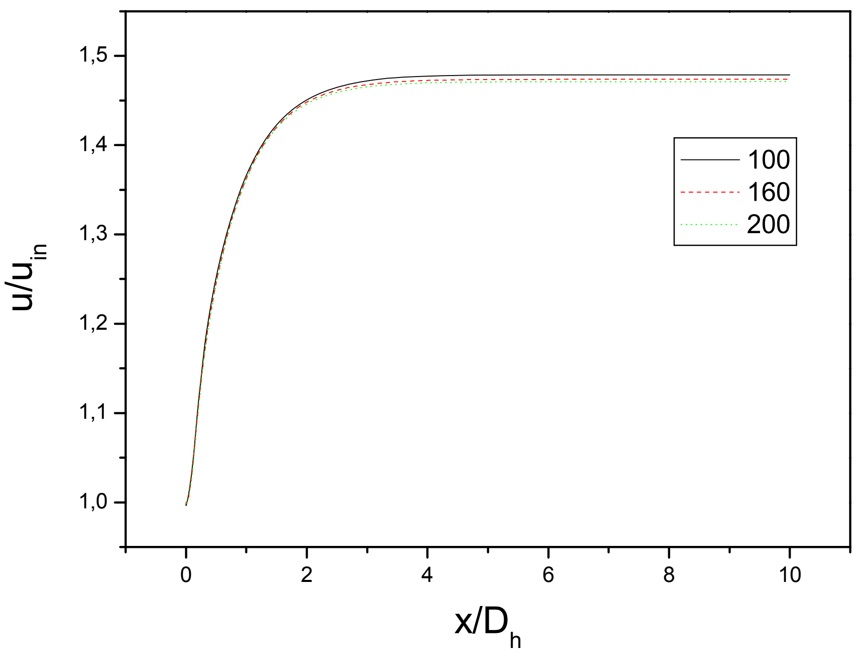
Velocity- Pressure coupling method

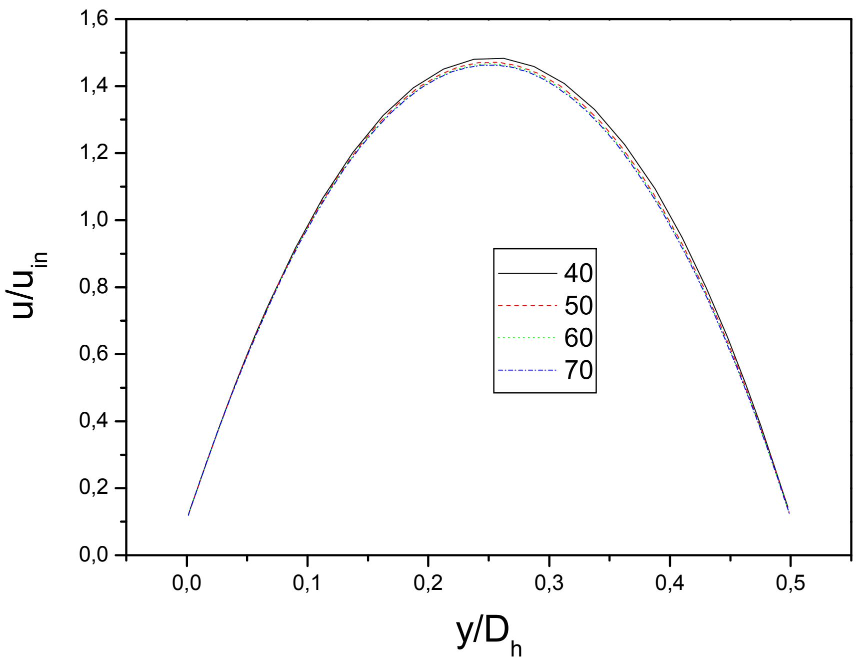
- *SIMPEL (Semi-Implicit Method for Pressure-Linked Equations)*
- *SIMPLER*
- *SIMPLEC*
- *SIMPLEX*
- …

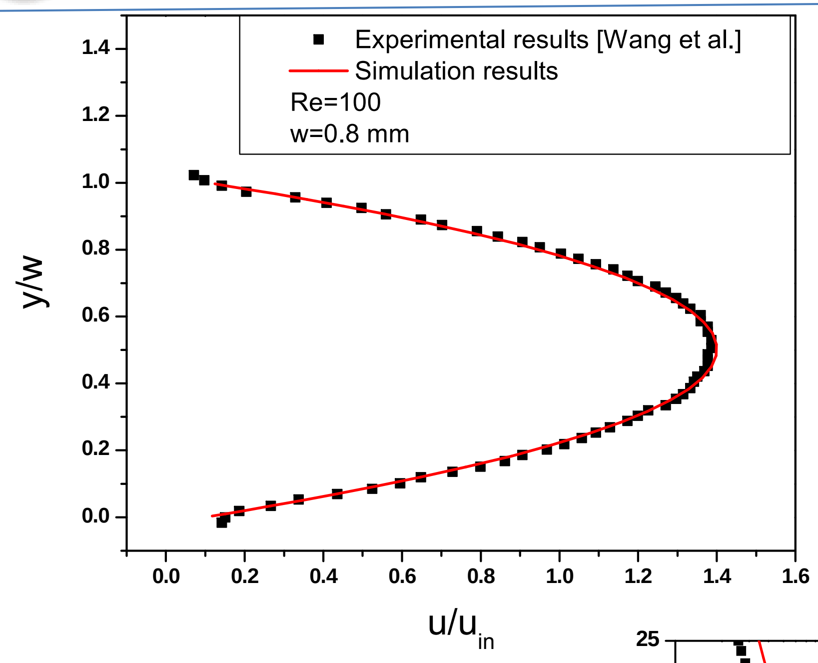
Numerical procedure

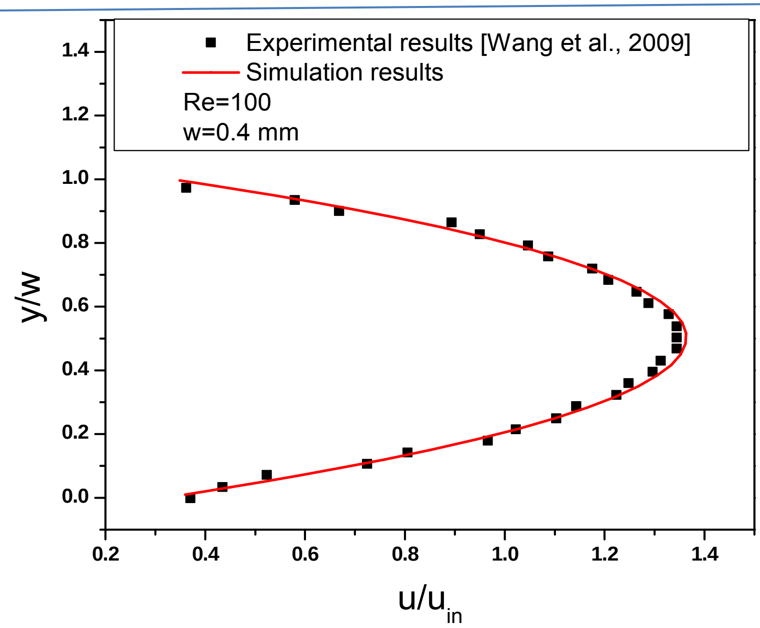
- *Control volume technique*
- *Power law scheme*
- *SIMPLER*
- The discretization grid is non-uniform. It is finer near the tube entrance and near the wall where the velocity and temperature gradient are significant.

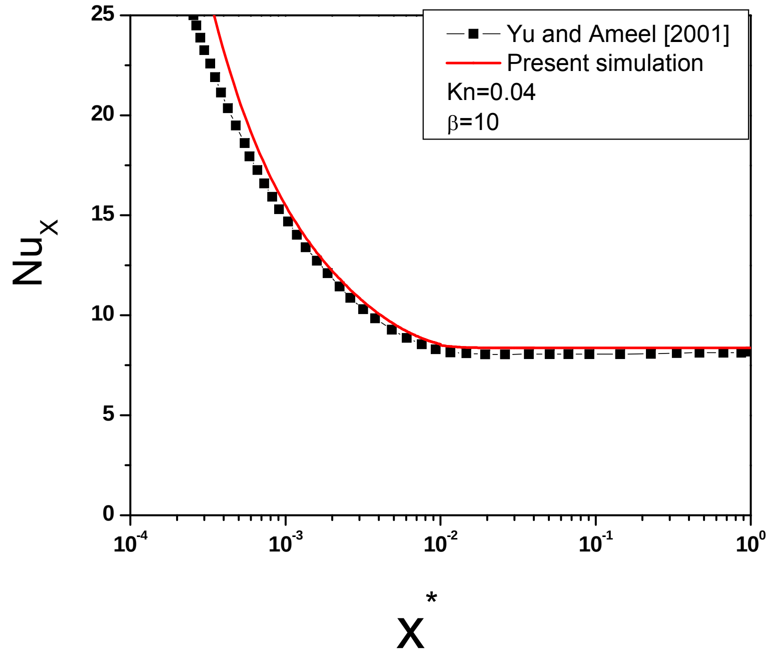
Validation and Comparison



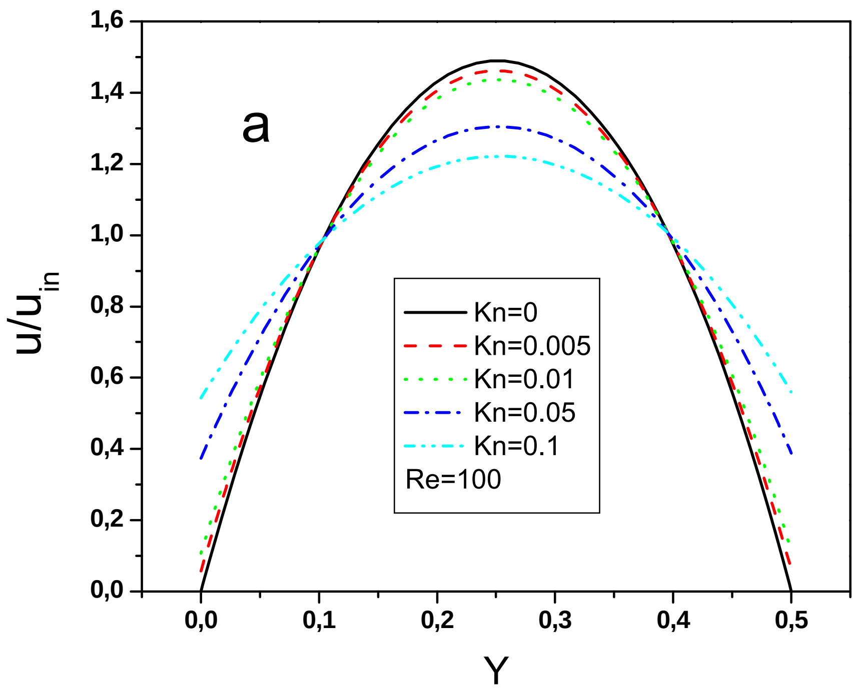


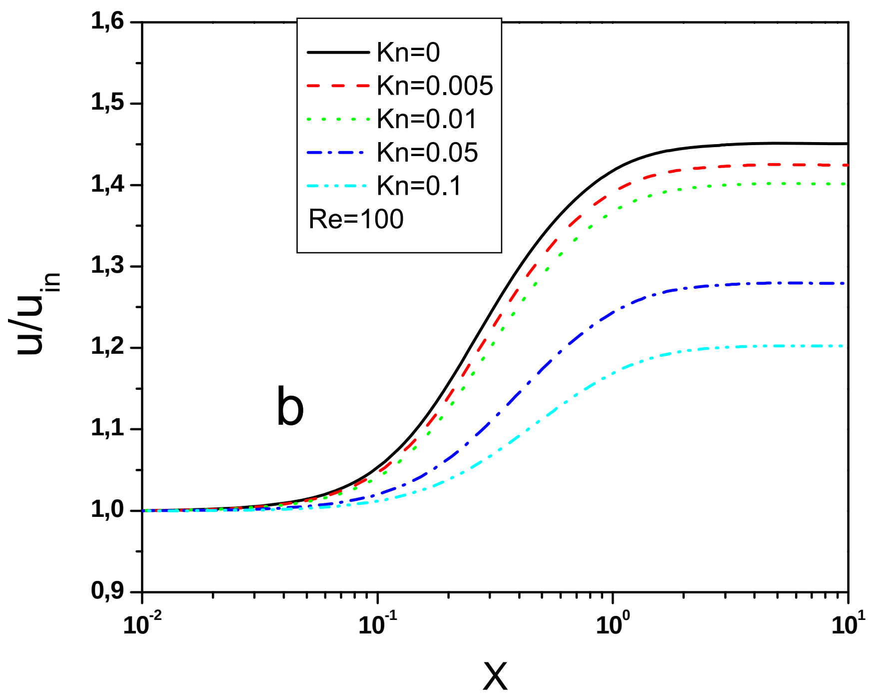

Experimental results [Wang et al.]
Simulation results
Re=100
w=0.8 mm
y/w
u/u_in
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

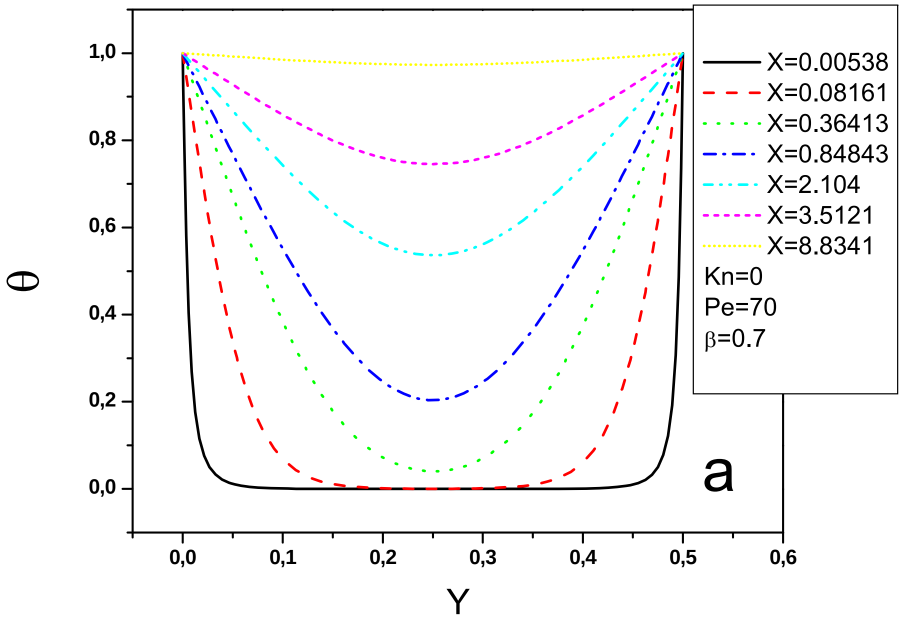

Experimental results [Wang et al., 2009]
Simulation results
Re=100
w=0.4 mm
y/w
u/u_in
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

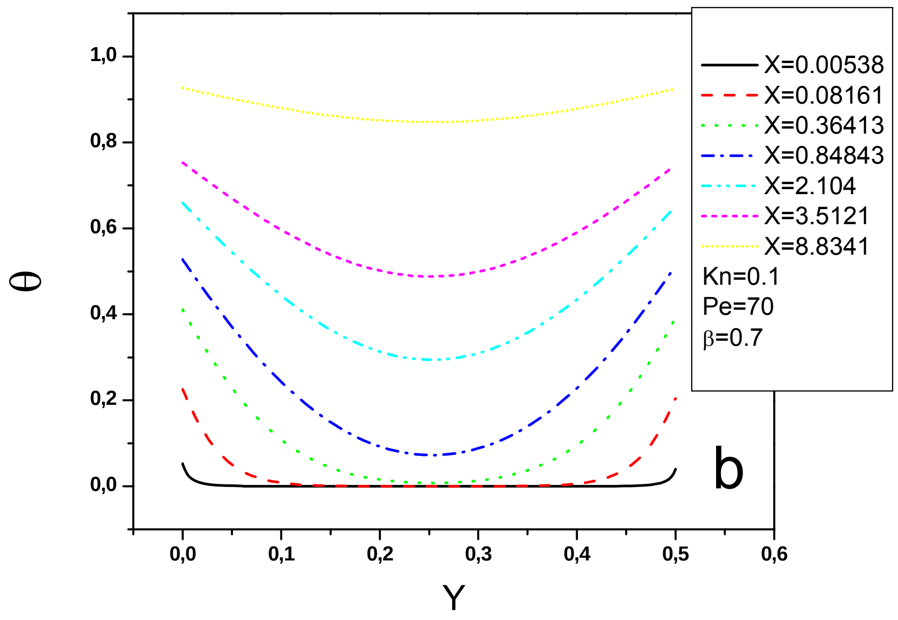

Yu and Ameel [2001]
Present simulation
Kn=0.04
β=10
Nu_X
x*
0
5
10
15
20
25
10^-4
10^-3
10^-2
10^-1
10^0

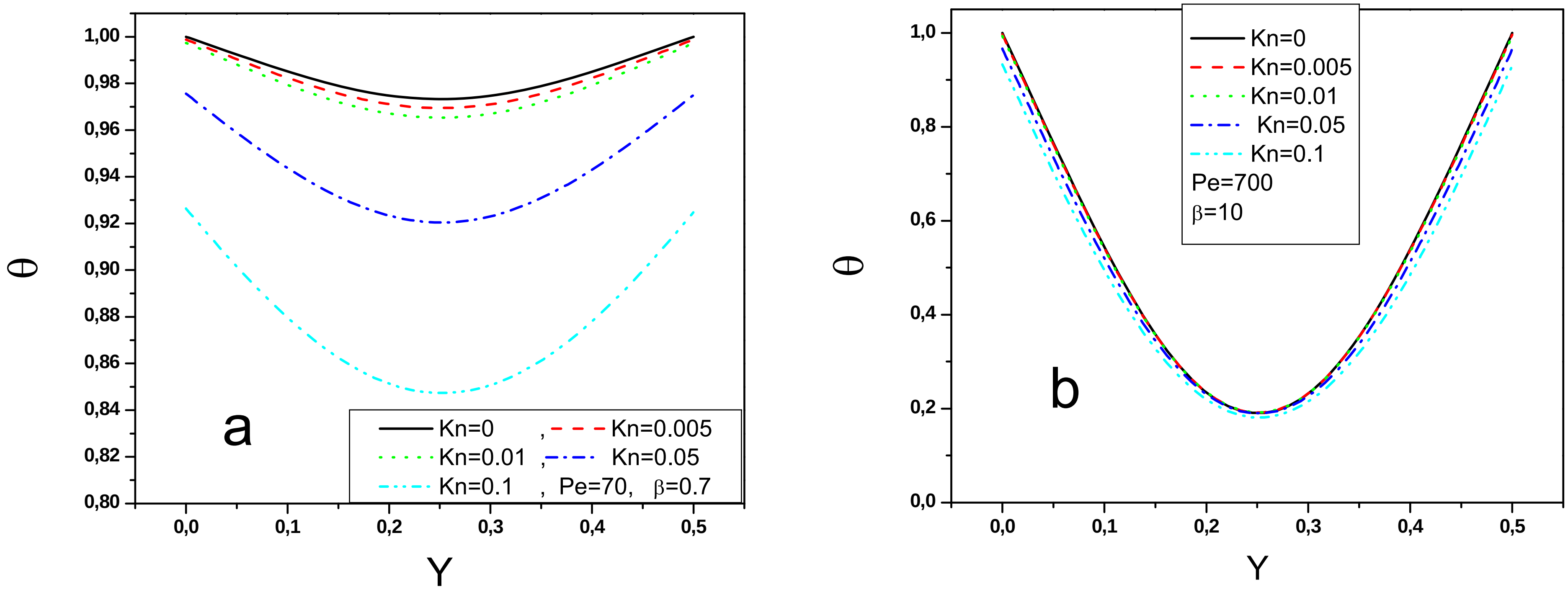
Results

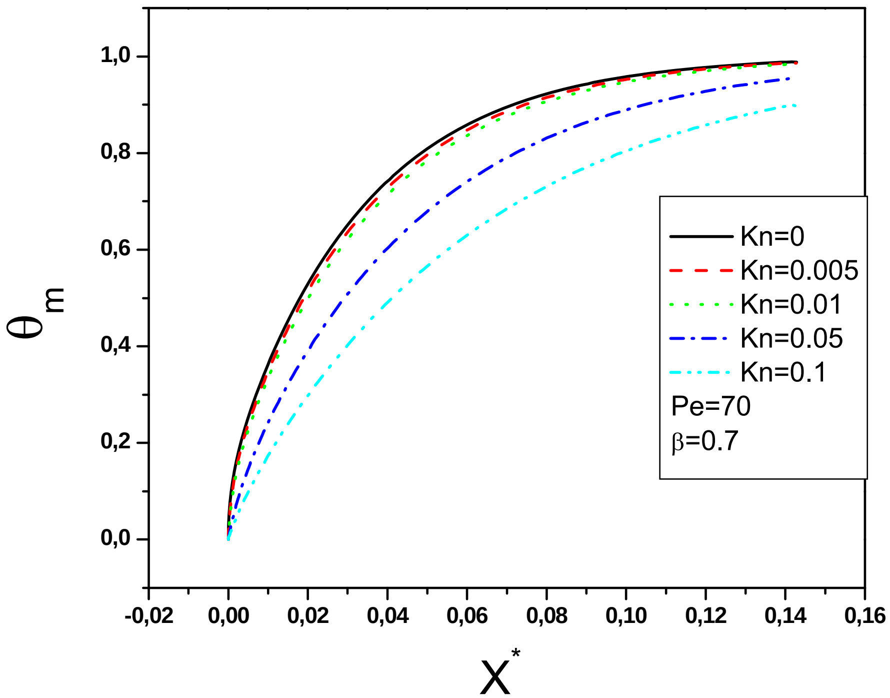

a
u/u_in
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0,0
0,1
0,2
0,3
0,4
0,5
Y
Kn=0
Kn=0.005
Kn=0.01
Kn=0.05
Kn=0.1
Re=100

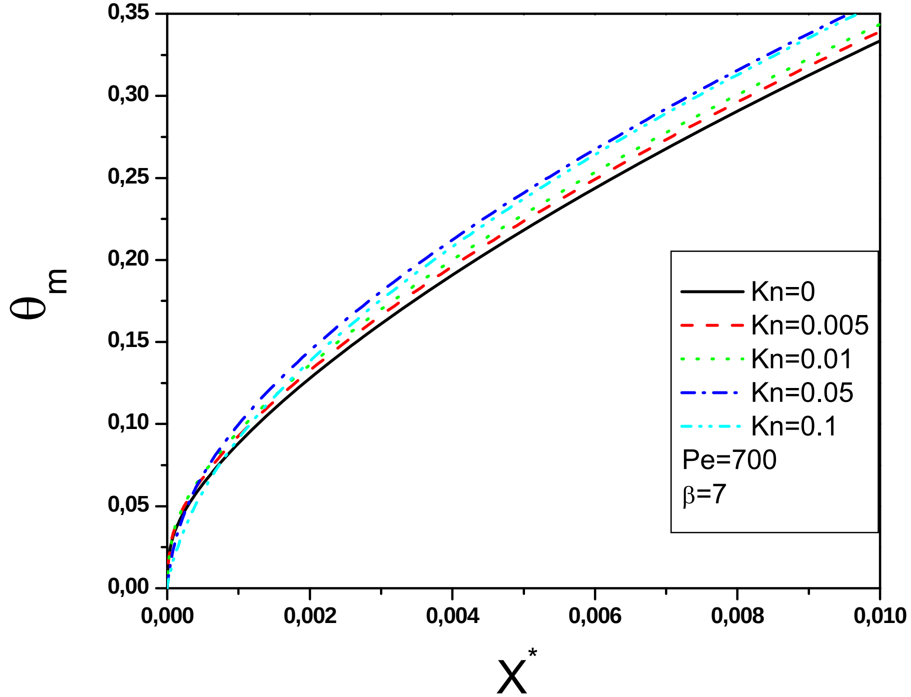

b
u/u_in
1,6
1,5
1,4
1,3
1,2
1,1
1,0
0,9
10^-2
10^-1
10^0
10^1
X
Kn=0
Kn=0.005
Kn=0.01
Kn=0.05
Kn=0.1
Re=100

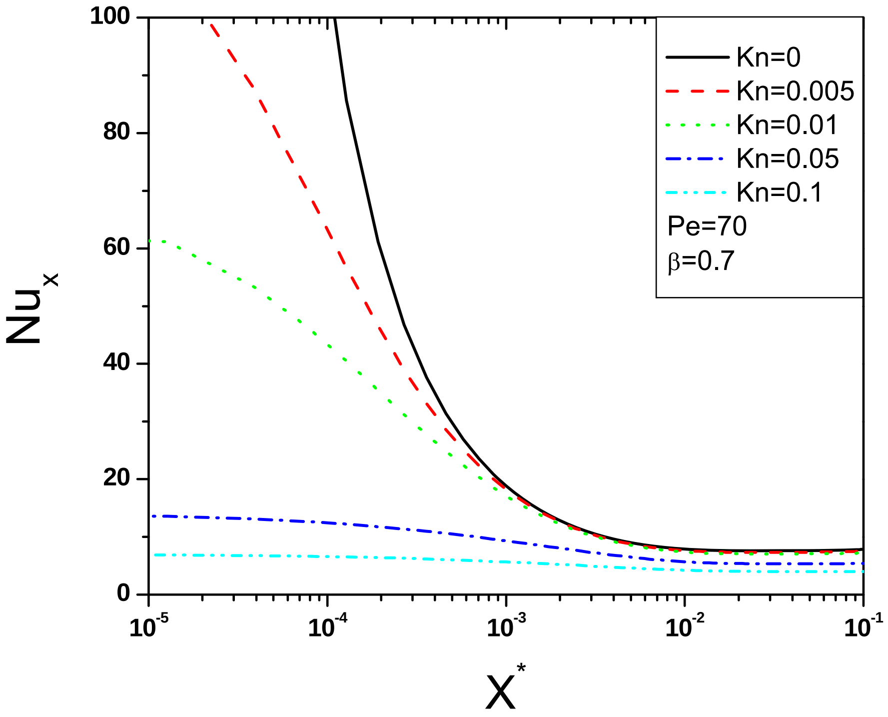

1,0
0,8
0,6
0,4
0,2
0,0
θ
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Y
X=0.00538
X=0.08161
X=0.36413
X=0.84843
X=2.104
X=3.5121
X=8.8341
Kn=0
Pe=70
β=0.7
a

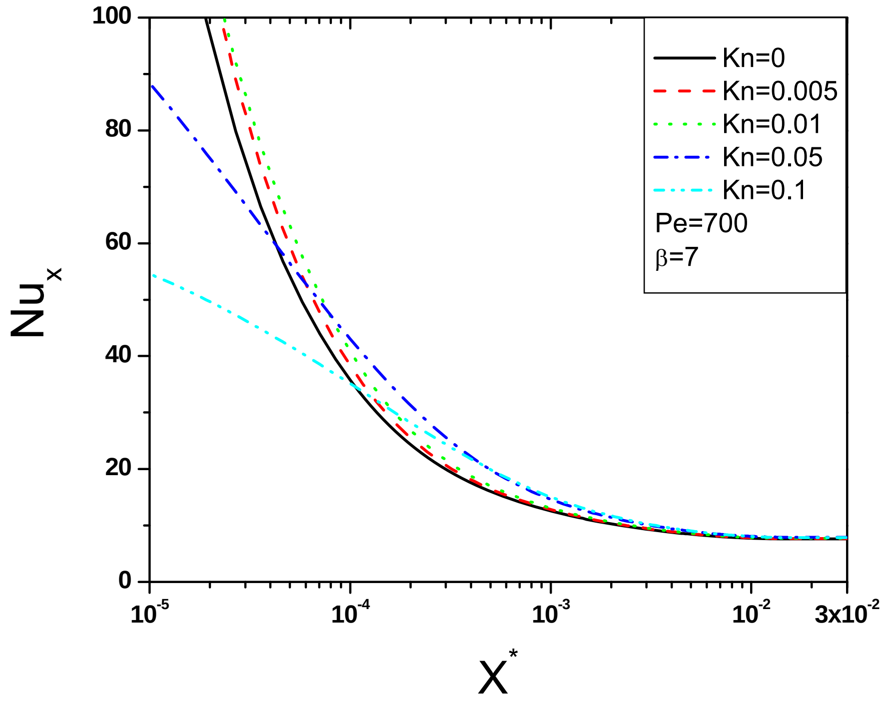

1,0
0,8
0,6
0,4
0,2
0,0
θ
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Y
X=0.00538
X=0.08161
X=0.36413
X=0.84843
X=2.104
X=3.5121
X=8.8341
Kn=0.1
Pe=70
β=0.7
b

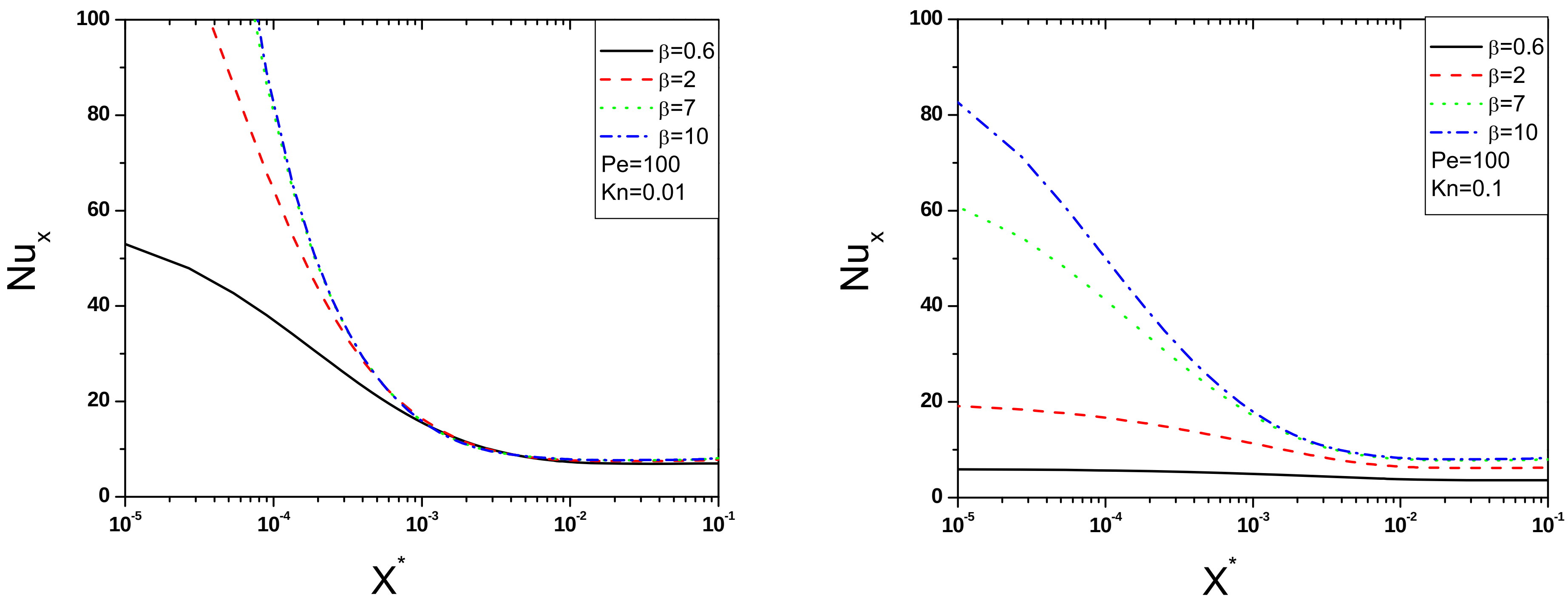

θ
Y
a
Kn=0 , Kn=0.005
Kn=0.01 , Kn=0.05
Kn=0.1 , Pe=70, β=0.7
1,00
0,98
0,96
0,94
0,92
0,90
0,88
0,86
0,84
0,82
0,80
0,0
0,1
0,2
0,3
0,4
0,5
θ
Y
b
Kn=0
Kn=0.005
Kn=0.01
Kn=0.05
Kn=0.1
Pe=700
β=10
1,0
0,8
0,6
0,4
0,2
0,0
0,0
0,1
0,2
0,3
0,4
0,5


θm
X*
Kn=0
Kn=0.005
Kn=0.01
Kn=0.05
Kn=0.1
Pe=70
β=0.7
1,0
0,8
0,6
0,4
0,2
0,0
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12
0,14
0,16


θm
X*
Kn=0
Kn=0.005
Kn=0.01
Kn=0.05
Kn=0.1
Pe=700
β=7
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
0,000
0,002
0,004
0,006
0,008
0,010


Nux
X*
Kn=0
Kn=0.005
Kn=0.01
Kn=0.05
Kn=0.1
Pe=70
β=0.7


Nux
X*
Kn=0
Kn=0.005
Kn=0.01
Kn=0.05
Kn=0.1
Pe=700
β=7


100
80
60
40
20
0
Nu_x
10^-5
10^-4
10^-3
10^-2
10^-1
X*
β=0.6
β=2
β=7
β=10
Pe=100
Kn=0.01
100
80
60
40
20
0
Nu_x
10^-5
10^-4
10^-3
10^-2
10^-1
X*
β=0.6
β=2
β=7
β=10
Pe=100
Kn=0.1

Thanks for your consideration