Rarefied gas flow into vacuum through a short tube

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Outline

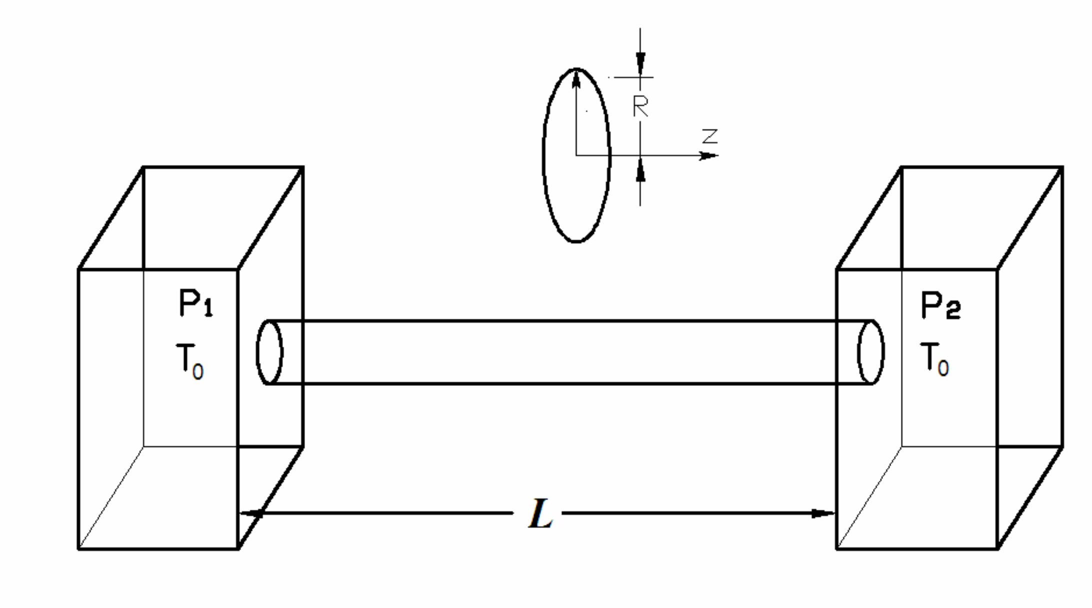
1. Introduction
2. Statement of the problem
3. Solution methodology
4. Results and discussion
5. Concluding remarks

1. Introduction

- In the present work the flow of a rarefied gas through a short tube into vacuum is investigated in the whole range of the Kn number.
- We choose to circumvent the direct solution of the BE (or kinetic models) and implement the DSMC method.
- Rarefied flows through orifices (Sharipov, 2004) and short tubes (Lilly, et al., 2006) capture a lot of theoretical interest due to their implementation to several industrial applications.

2. Statement of the problem

Flow of a monatomic gas through a short tube into vacuum.



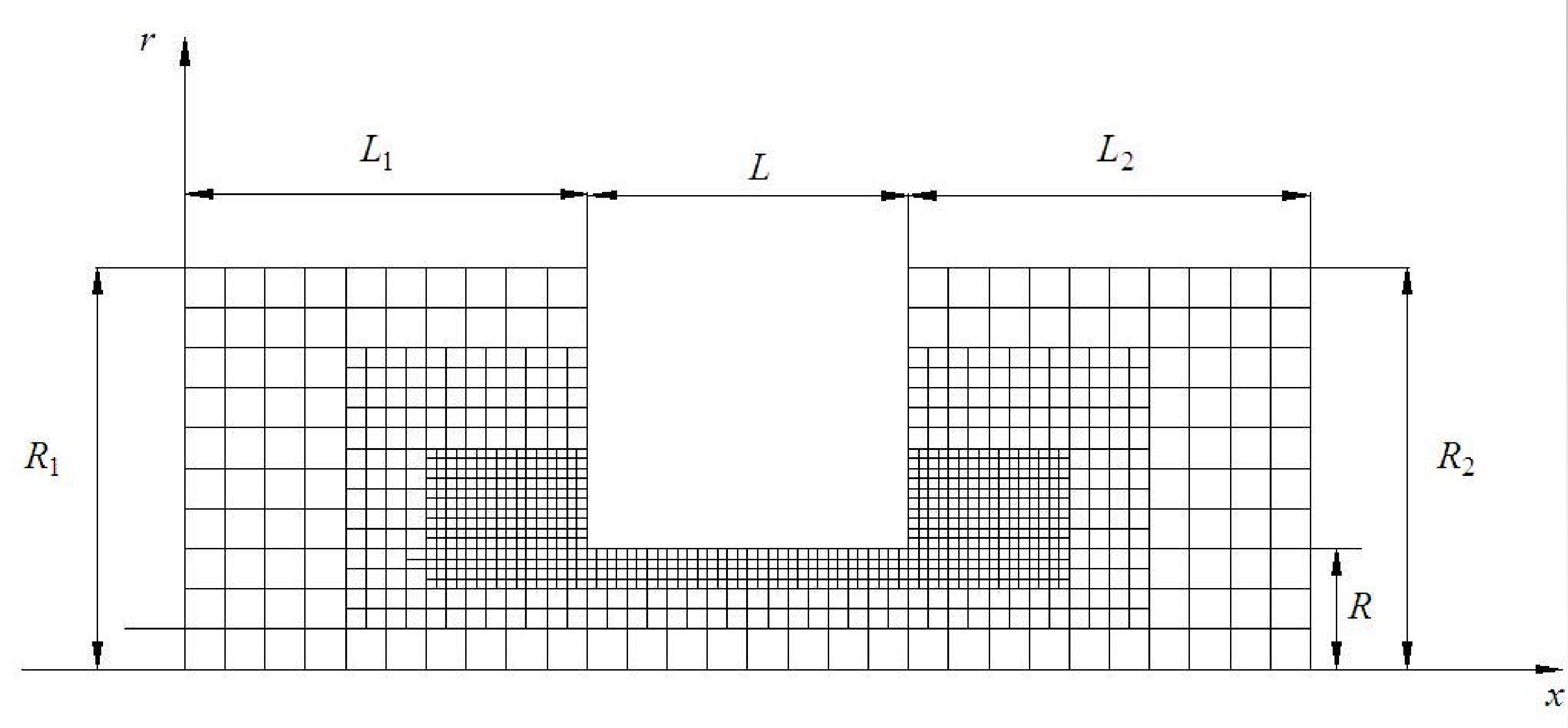
$$d = \frac{P_1 R}{m u_0}$$

$$P_2 / P_1 = 0$$

$$L/R = 0.1,\ 0.5,\ 1,\ 5,\ 10$$

$$d = 0,\ 0.1,\ 1,\ 10,\ 20,\ 50,\ 100,\ 1000$$

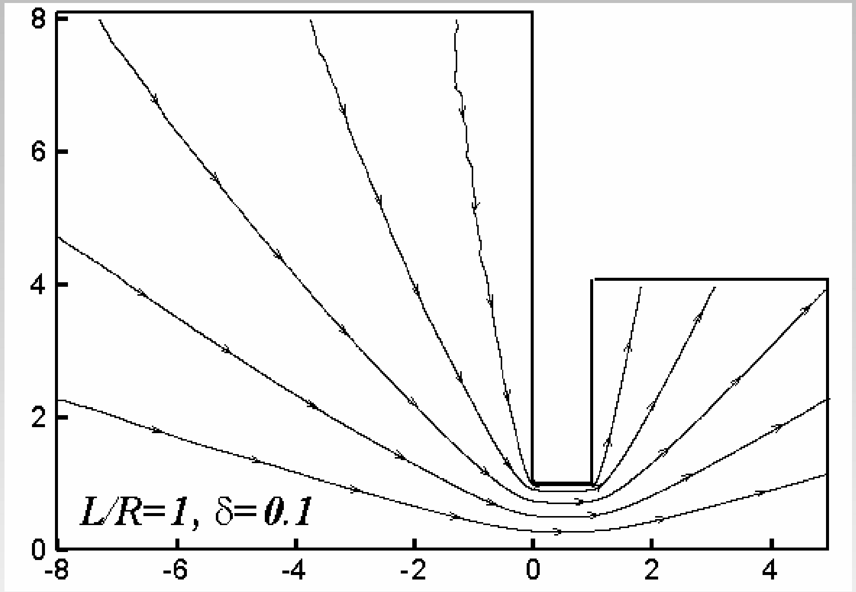
Computational Grid

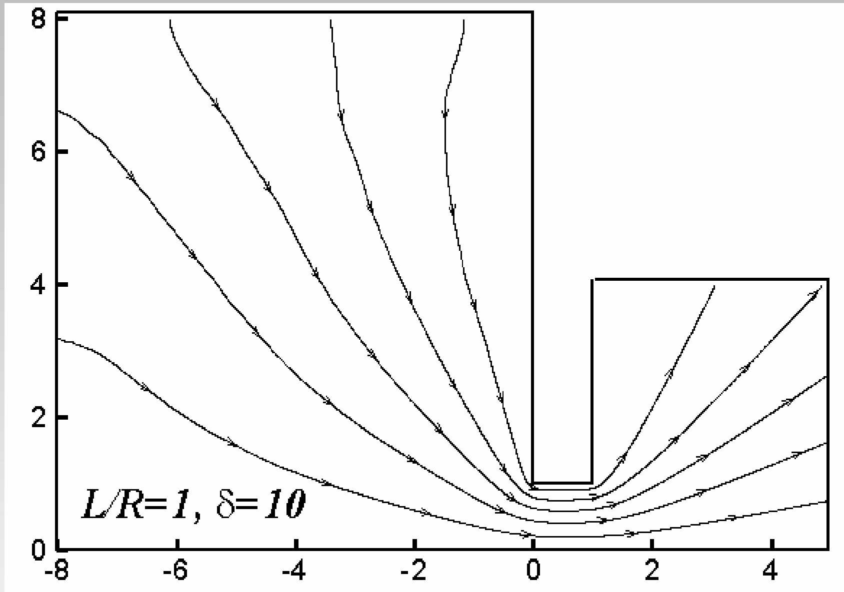


3. Solution methodology

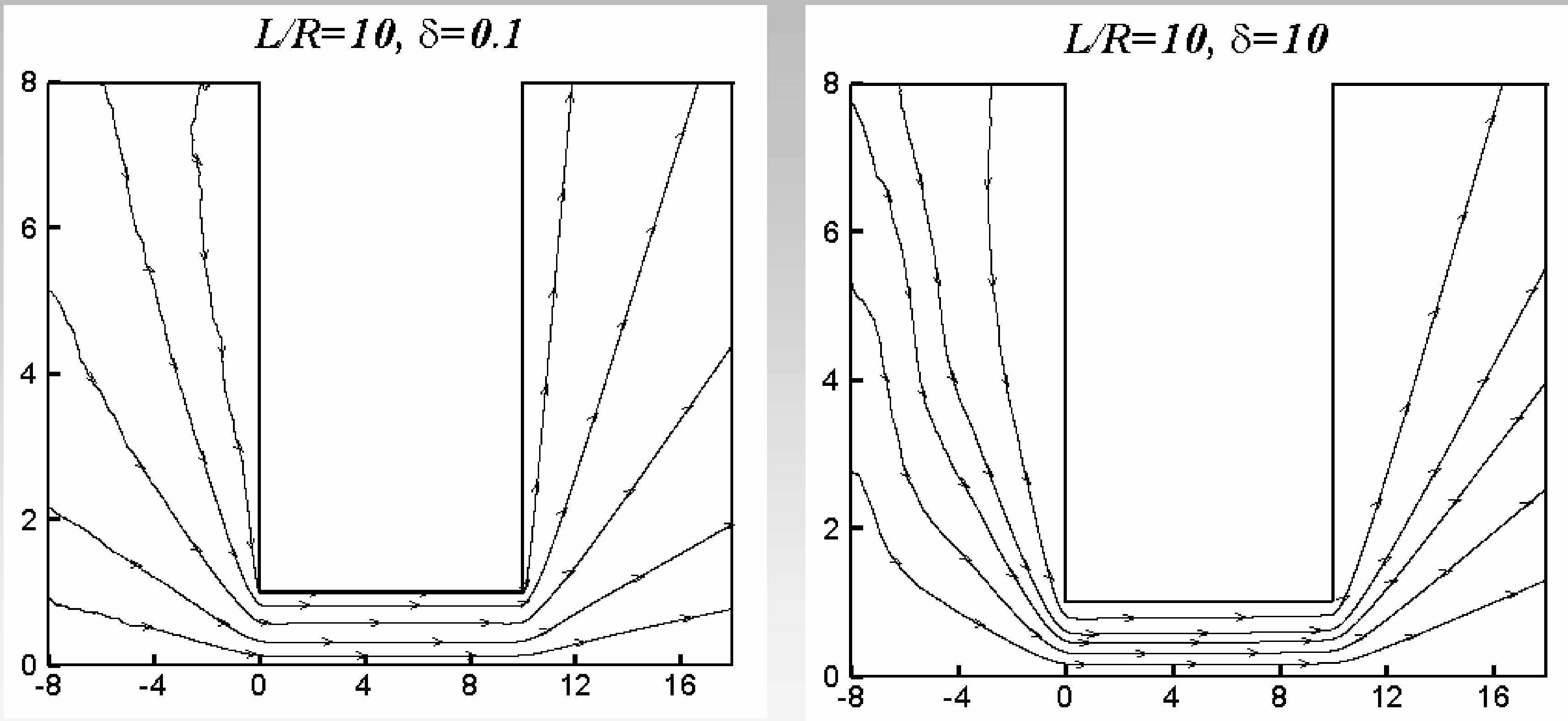
- A three-level computational grid has been adopted to provide better resolution near the walls and in the inlet and outlet of the tube.
- Several weighting zones have been used in the axial and radial direction to avoid non-uniform distributions of the model particles over the flow field.
- Several sizes of computational region before and after the tube have been tested and the ones finally selected ($L_1/R= R_1/R$=8, $L_2/R= R_2/R$=4 or 8) guarantee the invariance of the results in two significant figures.
- The number of simulated particles is about $25x10^6$.
- The discrete time step is 0.01 of the mean collision time and the statistical error in *W* is maintained less than 1%.

4. Results and discussion

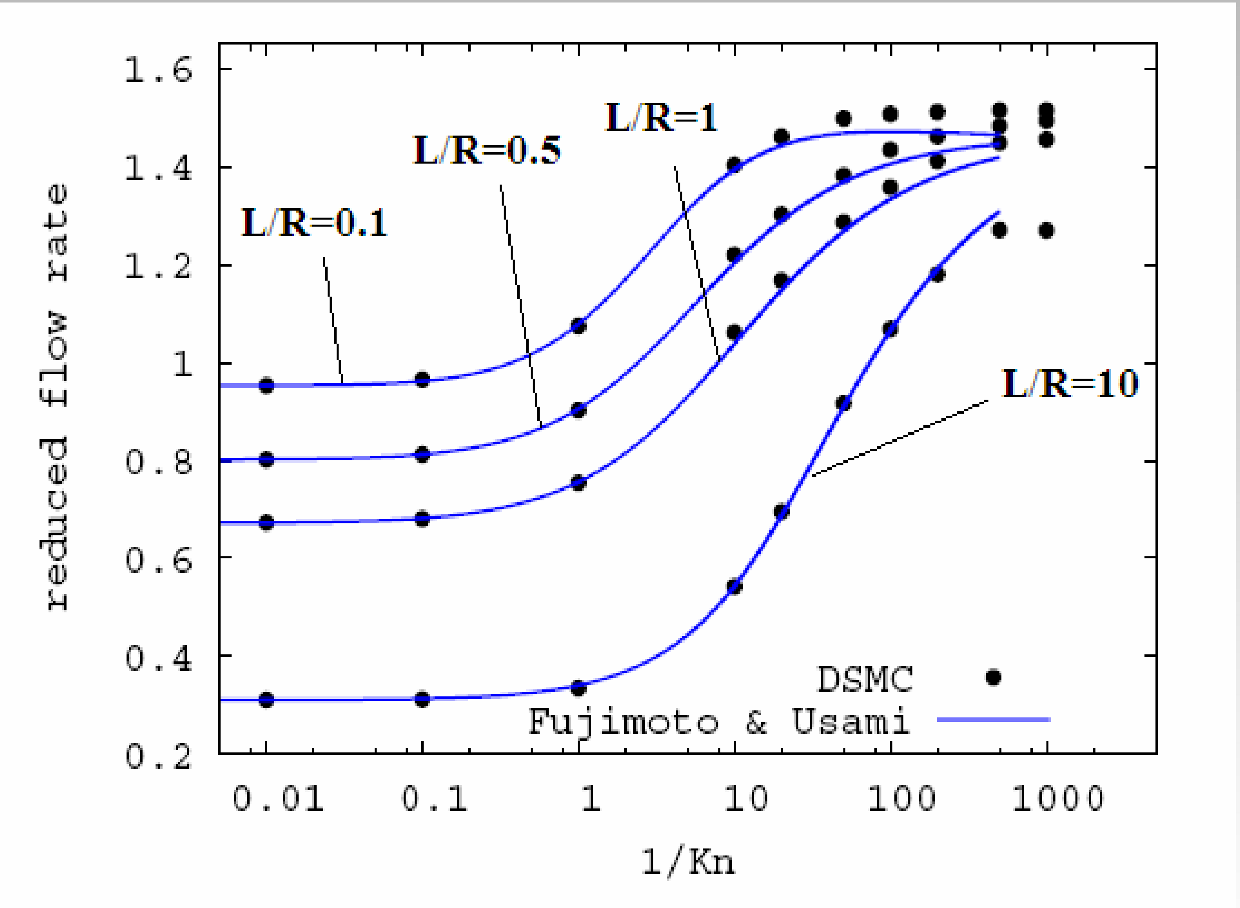




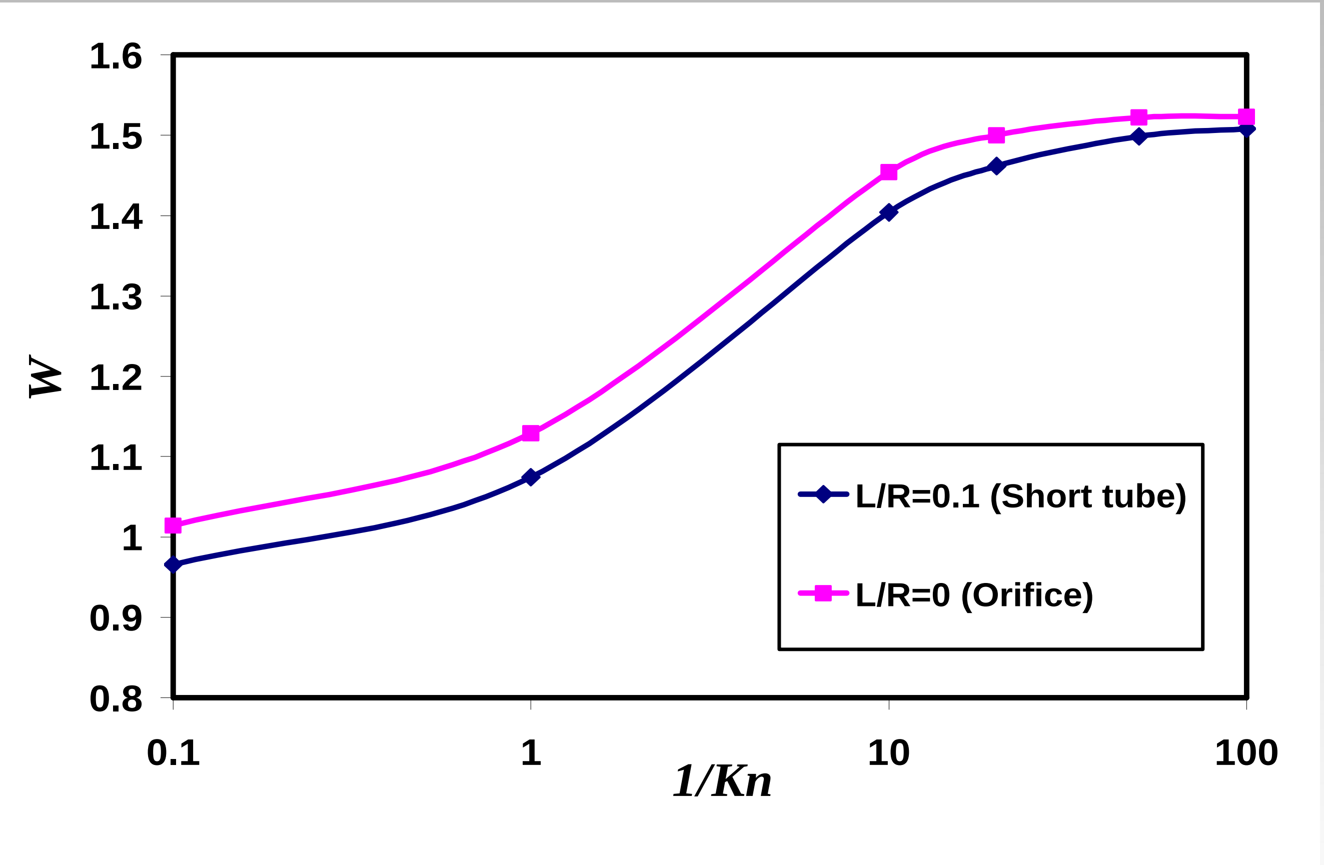
Velocity streamlines for *L/R*=1, *d*=0.1 (left) and *d*=10 (right)



Velocity streamlines for *L/R*=10, *d*=0.1 (left) and *d*=10 (right)



Reduced flow rate *W* in terms of *1/Kn* and comparison with experimental results



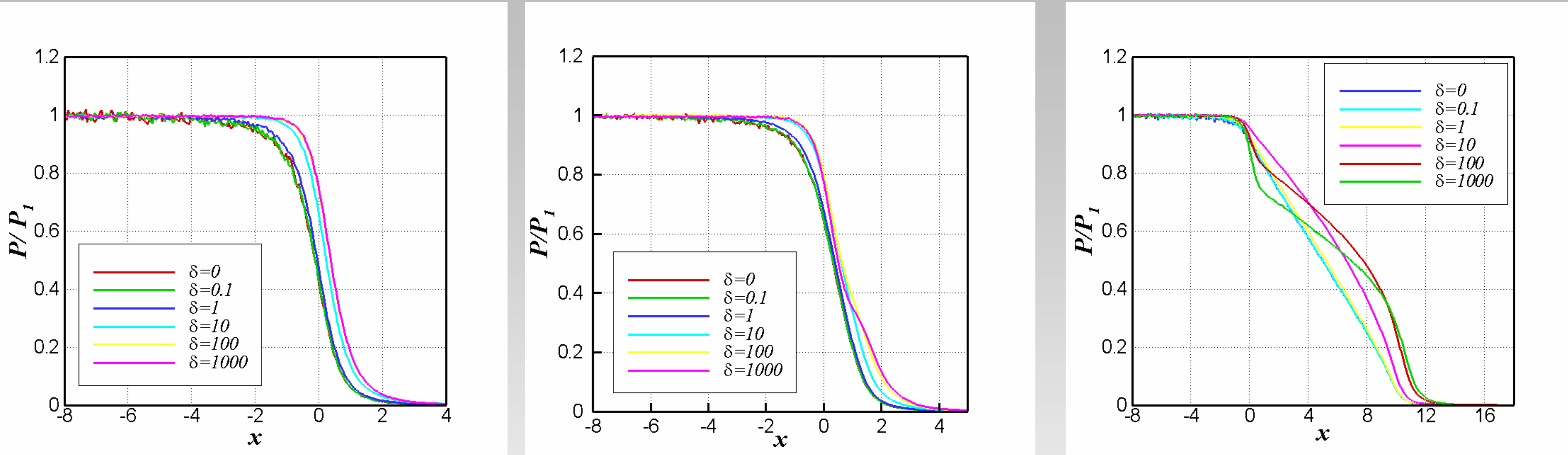
Reduced flow rate *W* in terms of *1/Kn* for an orifice and a short tube with *L/R*=0.1

4. Results and discussion

L/R	δ	W Diffuse (HS)	C-L (HS)	Diffuse (VHS, He)
0.1	0.1	0.9655	0.983	0.9628
	1	1.0745	1.093	1.0626
	10	1.4040	1.415	1.3884
1	0.1	0.6804	0.802	0.6798
	1	0.7539	0.891	0.7463
	10	1.0617	1.183	1.0415
10	0.1	0.1903	0.343	0.1898
	1	0.1984	0.363	0.1973
	10	0.3346	0.493	0.3176

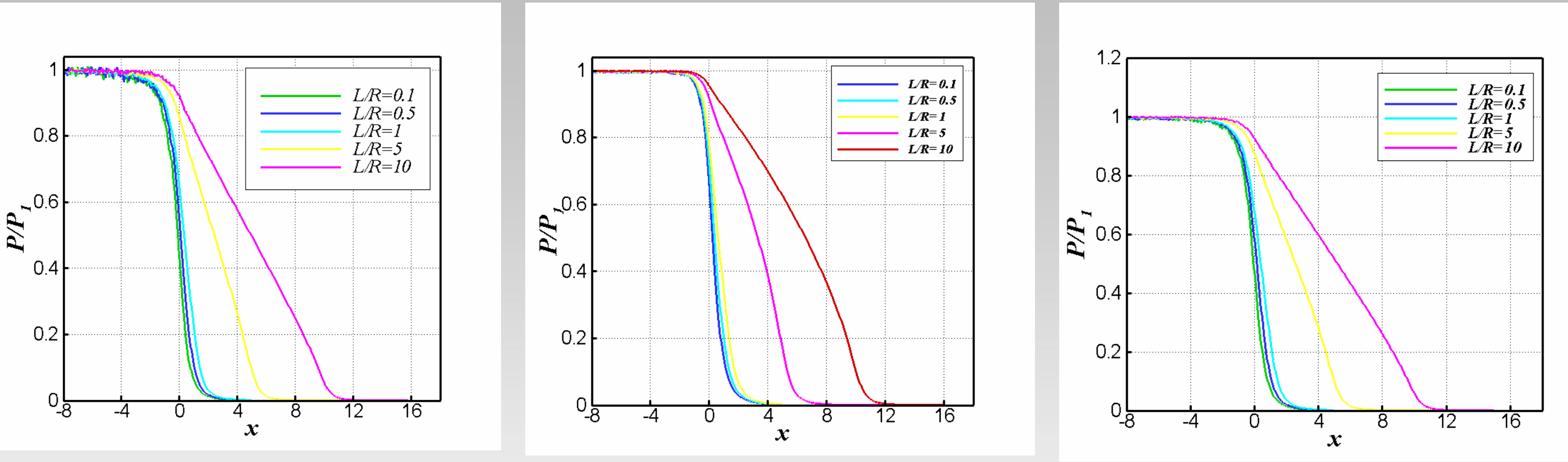
Reduced flow rate *W* for various boundary conditions and intermolecular potentials

4. Results and discussion



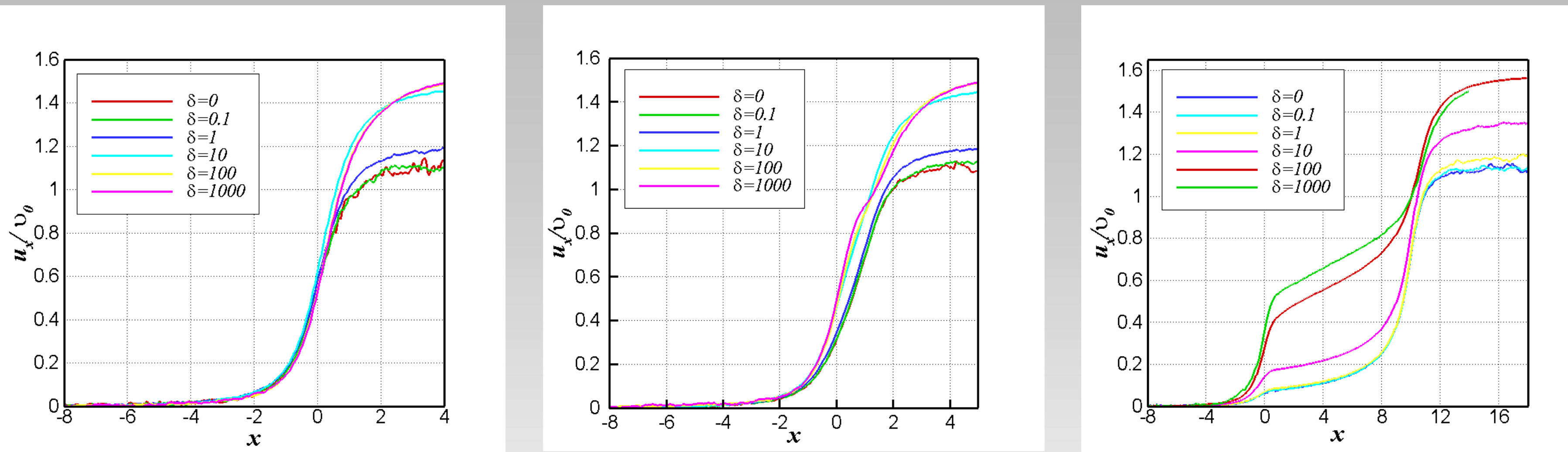
Pressure distribution along the axis of the flow field
for various *d* and *L/R* = 0.1, 1 and 10

4. Results and discussion



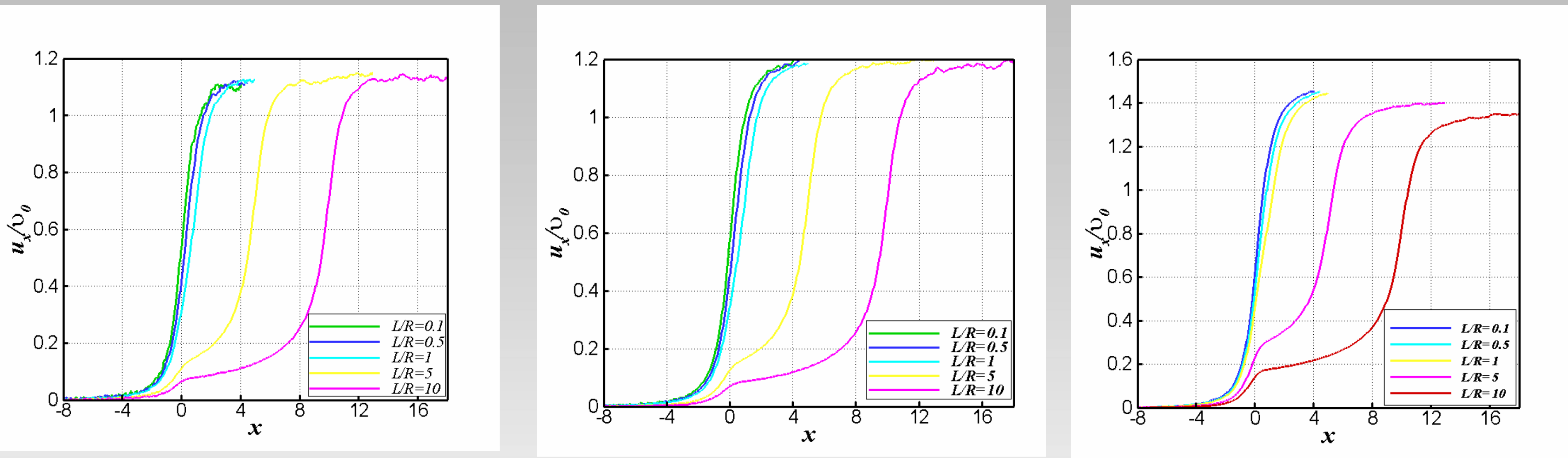
Pressure distribution along the axis of the flow field
for various *L/R* and *d* = 0.1, 1 and 10

4. Results and discussion



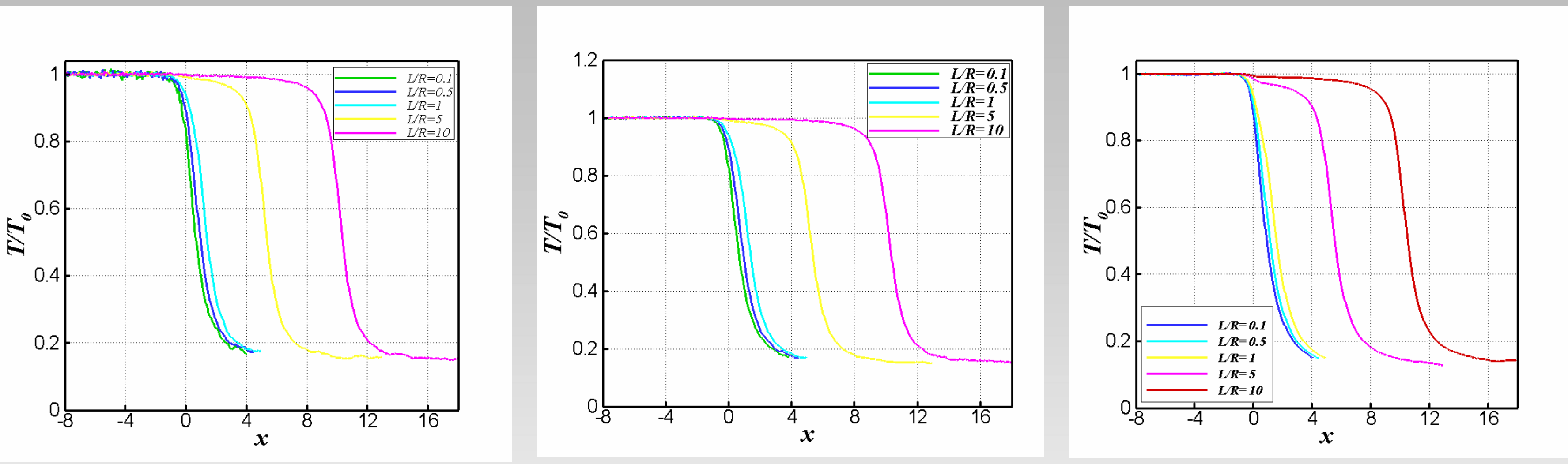
Axial velocity distribution along the axis of the flow field
for various *d* and *L/R* = 0.1, 1 and 10

4. Results and discussion

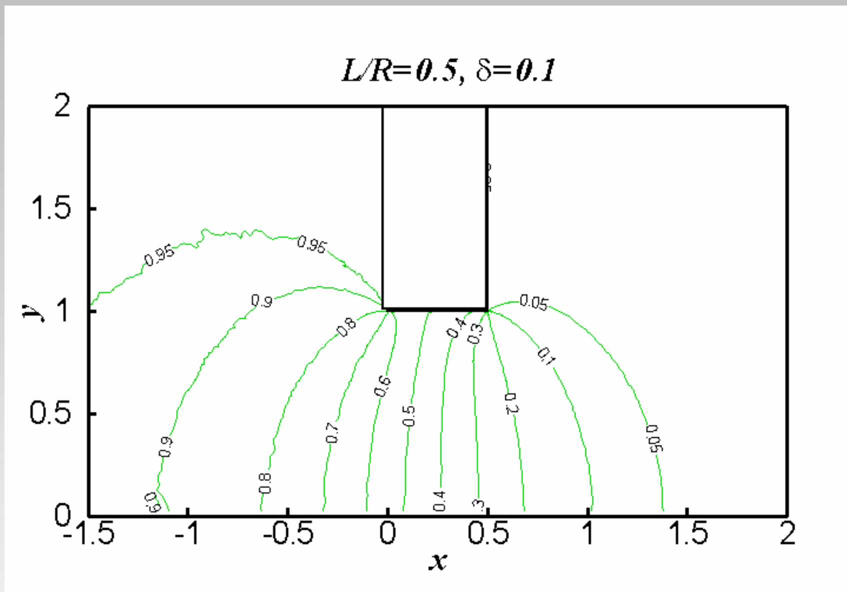


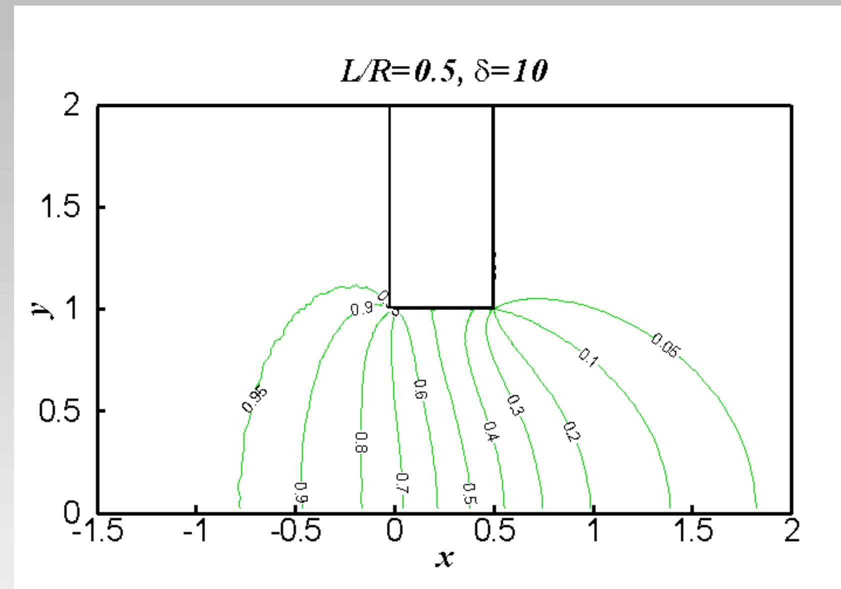
Axial velocity distribution along the axis of the flow field
for various *L/R* and *d* = 0.1, 1 and 10

4. Results and discussion



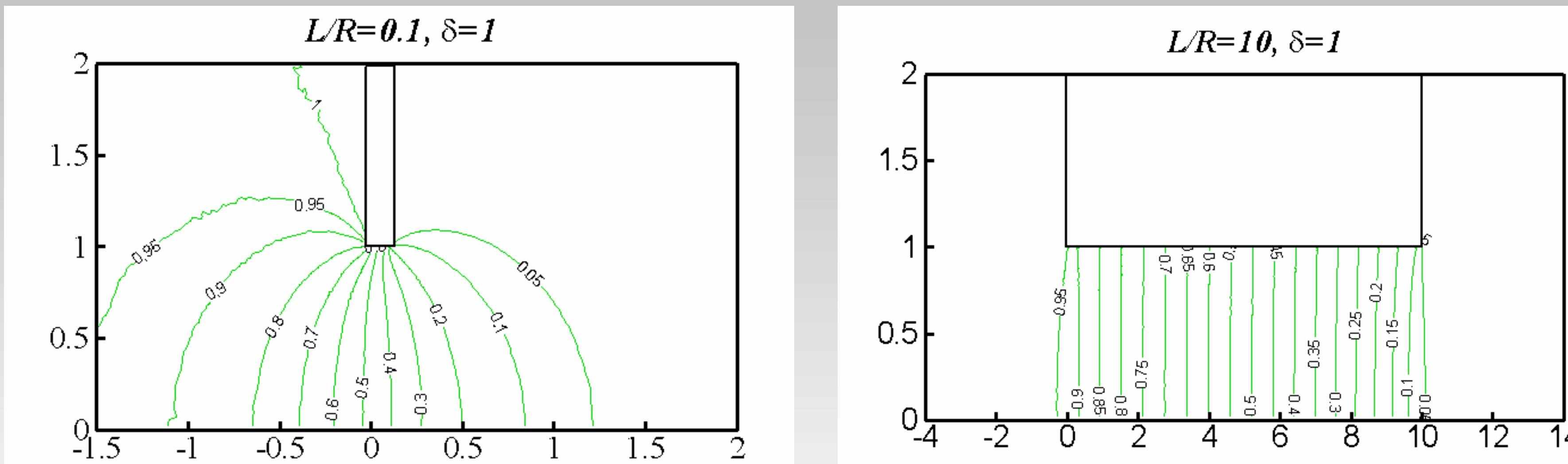
Temperature distribution along the axis of the flow field for various *L/R* and *d* = 0.1, 1 and 10



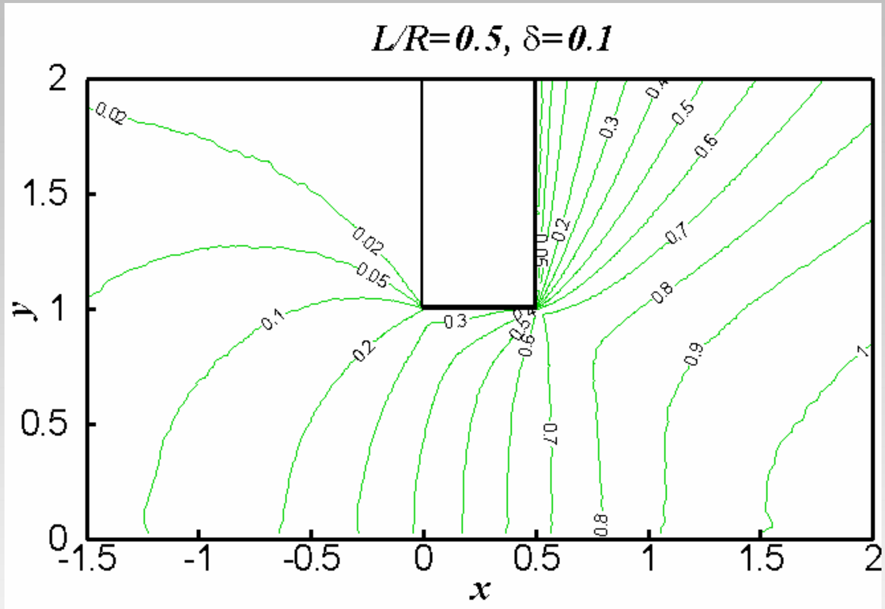


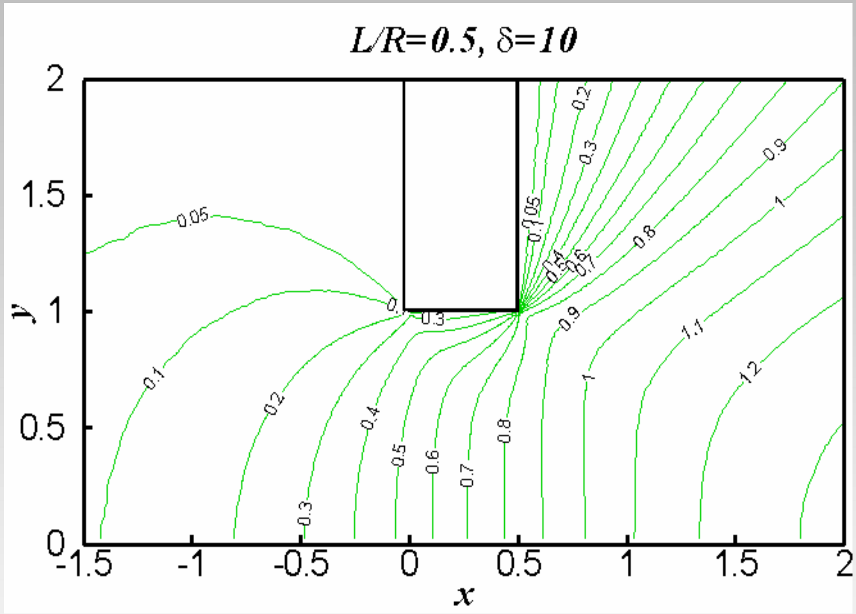
Pressure isolines in the region around and inside the tube
for L/R = 0.5 and d = 0.1 and 10

4. Results and discussion

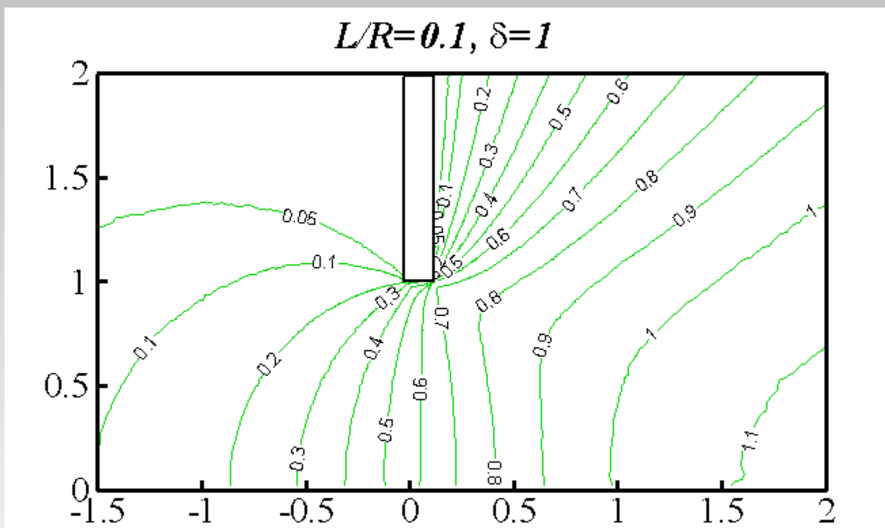


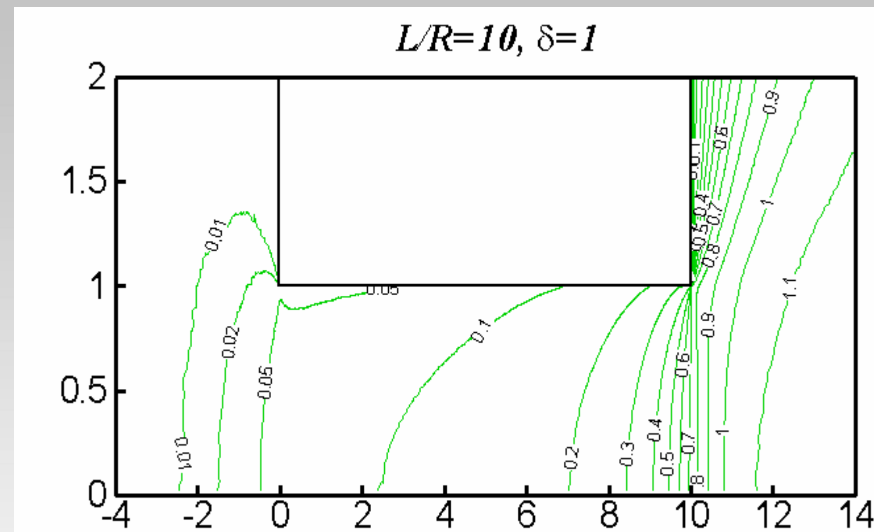
Pressure isolines in the region around and inside the tube
for d = 1 and L/R = 1 and 10





Isolines of axial velocity in the region around and inside the tube for *L/R* = 0.5 and *d* = 0.1 and 10





Isolines of axial velocity in the region around and inside the tube
for *d* = 1 and *L*/*R* = 1 and 10

4. Results and discussion

- The dependency of *W* on *d*, is clearly distinguished into three different regions. As *d* is increased, at small *d*, *W* is increased very slowly, at intermediate *d* there is a significant increase in *W* and finally at large *d*, *W* is increased very weakly reaching asymptotically the continuum result at the hydrodynamic limit. The values of *d* defining each region depend on *L/R*.
- As *L/R* is increased the conductance of the tube is significantly reduced.
- The dependency of *W* on the model describing gas – surface interaction becomes important as *L/R* is increased. Also, *W* is not sensitive to the molecular model.

4. Results and discussion

- Qualitatively, the corresponding gas flows through orifices (*L/R*=0) and short tubes are similar. Quantitatively, the flow rates for *L/R*=0.1 are about 5% less than the corresponding ones for the orifice flow and this deference is increased as *L/R* is increased.
- As expected the streamlines are symmetric at small *d*, while the symmetry breaks down at large *d*.
- Along the symmetry axis of the flow field, density and pressure are monotonically reduced from their equilibrium values (far upstream) to zero (far downstream), while the axial velocity is monotonically increased starting from zero (far upstream).
- There is good agreement with the experimental results (Fujimoto & Usami, 1984; Barashkin, 1977).

5. Concluding remarks

- The flow of rarefied gas through a short tube into vacuum has been investigated in the whole range of the *Kn* number by the DSMC method.
- Preliminary results including the reduced flow rate and distributions of axial velocity, pressure and temperature have been reported.
- The dependency of these quantities on the *Kn* number, the length *L/R* and the gas – surface interaction and molecular models has been examined.
- The present work will be extended to the cases of $P1/P2 \neq 0$ and to channels of various cross sections.

References

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4. S. Barashkin, Ph.D thesis, Ural State Tech University, 1977.

Acknowledgements

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