DSMC Simulation of Shear Driven Flow in Nano-Gap Structures

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Introduction

Shear driven nano-scale confined gas flows are encountered in the components of micro- and nano-electromechanical systems such as micro/nano-motor, comb mechanism, and micro/nano-bearing, and in magnetic disc drive units. For the latter, distance between the head and media is on the order of 10 nm, and the next generation disc drives strive to reduce this distance to enhance the magnetic storage capacity. Micro- and nano-Couette flow has been widely studied in the literature: Beskok et al. [2] reported a detailed analysis of the effects of compressibility and rarefaction on pressure-driven and shear-driven microflows. They found that compressibility and rarefaction are competing phenomena and both require consideration in microfluidic analysis. During the last decade many scientists compared different numerical tools in the Couette flow [3-6]. In the present work we investigate rarefaction effects on velocity, temperature, heat flux, shear stress and entropy profiles. The specific contribution of this work is detailed discussion on heat flux and shear stress behavior of the gas besides calculation of entropy as a thermodynamics property using microscopic formulation, to show the molecular disorder in the channel .

Modeling

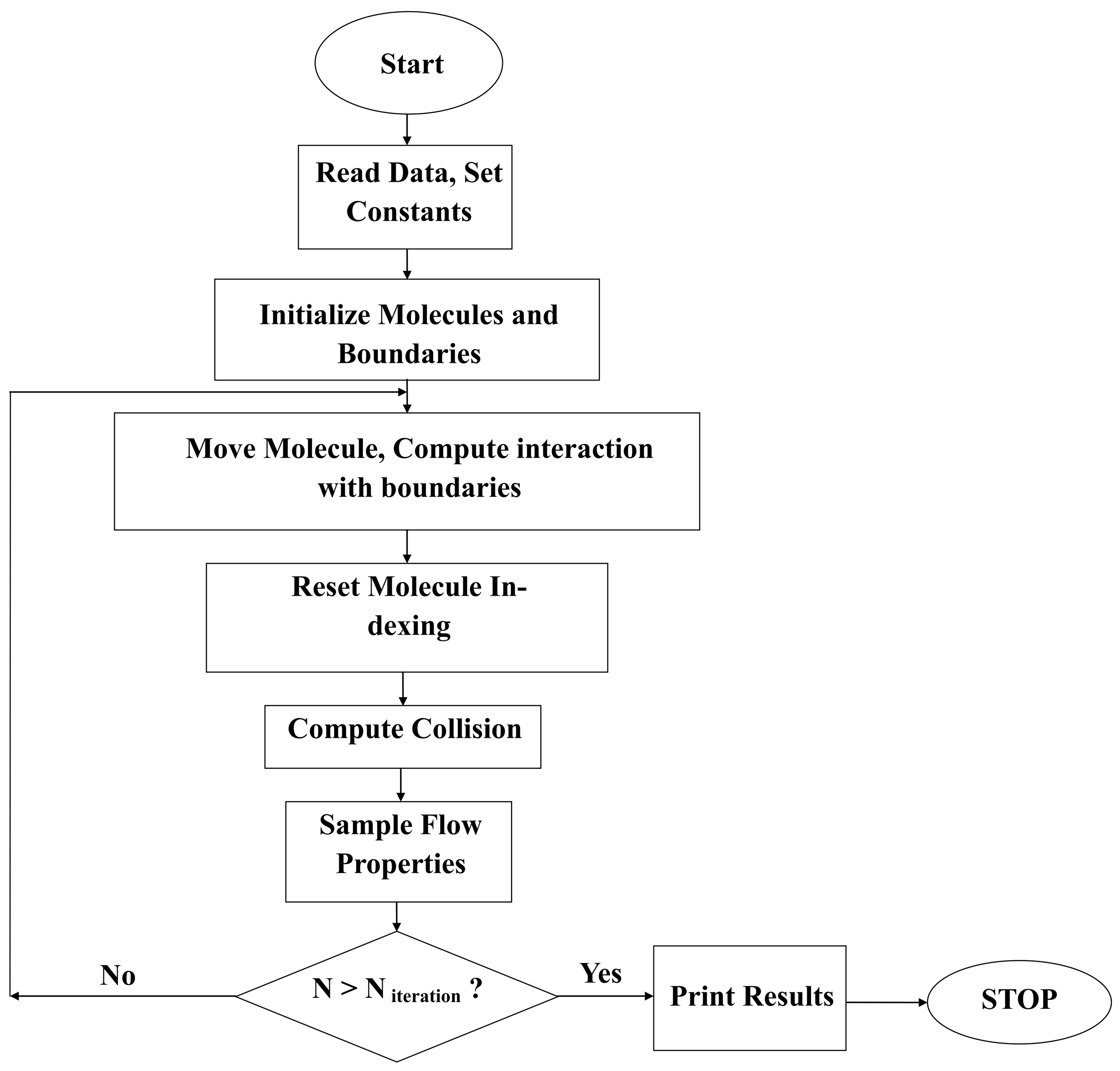

Fig.1- DSMC Flowchart

Results and Discussion

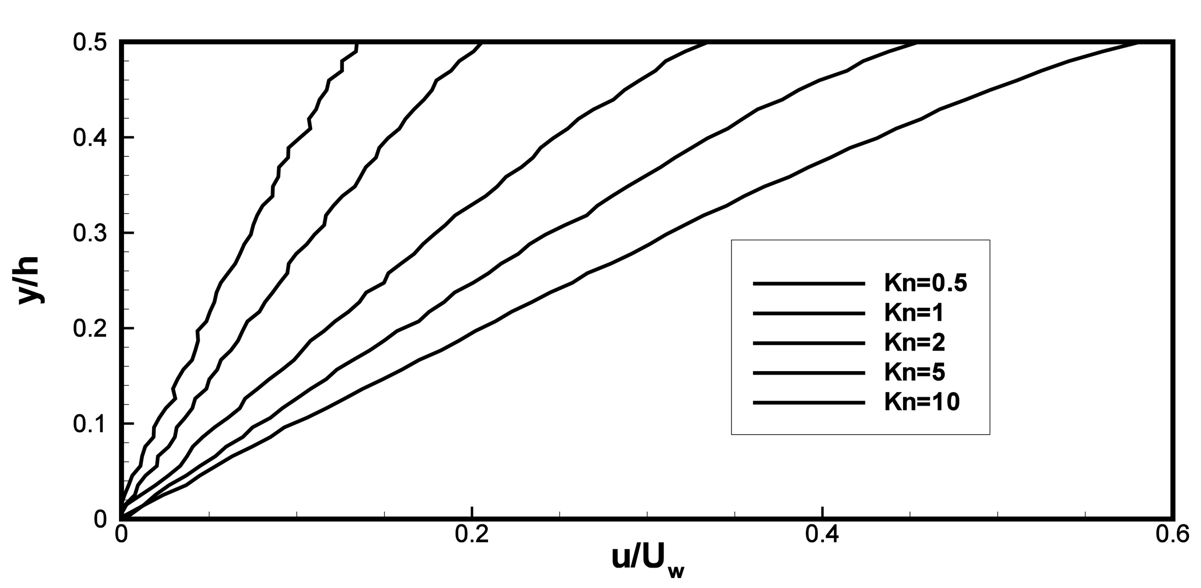

Fig.2- Rarefaction Effects on Velocity Profiles

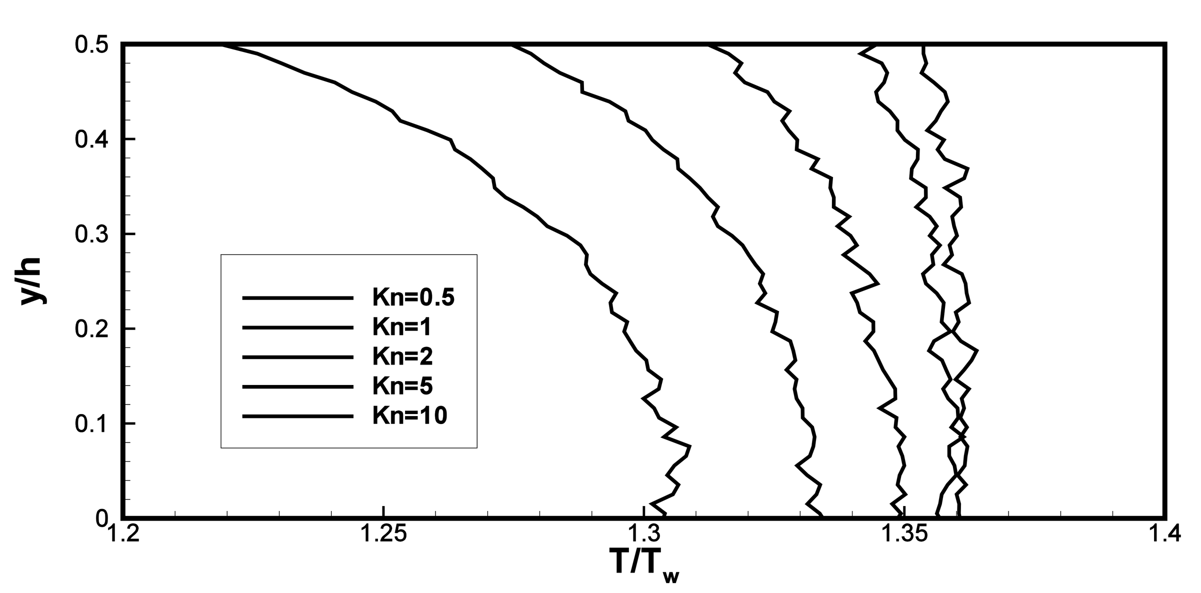

Fig.3- Rarefaction Effects on Temperature Profiles

Results and Discussion(Continued)

Rarefaction effects gain importance with the reduction in the geometry size. It is observed in Fig.2 that the slope of velocity profile decreases as Knudsen number increases. This means decrease of velocity in the domain. It can be seen that a kinetic boundary layer named *Knudsen layer* on the order of one to a few mean free paths starts to become dominant between the bulk flow and solid surfaces in the transition flow regime. The velocity profile and other physical variables are subject to appreciable changes within the Knudsen layer.

Figure 3 illustrates the temperature profiles at different Knudsen numbers. As the Knudsen number increases, temperature in the domain and also temperature jump at the plates becomes more significant, but the curvature of temperature profiles reduces. In a constant wall Mach number flow, the amount of wall kinetic energy is constant. As the flow becomes more rarefied, this constant kinetic energy will be saved in smaller number of the molecules and shows itself in term of temperature rise. Figure 4 shows the non-dimensional heat flux variation in x and y direction. An interesting non-equilibrium phenomenon that occurs in planar Couette flow is the appearance of a heat flux without the presence of a temperature gradient, i.e. in x direction, and this is called nongradient transport. Our simulations show that as the gas becomes more rarefied, it would experience less shear stress due to smaller amount of intermolecular collisions. However, the magnitude of non-dimensional shear stress would still increase as observed in Fig. 5 for all components of shear stress tensor.

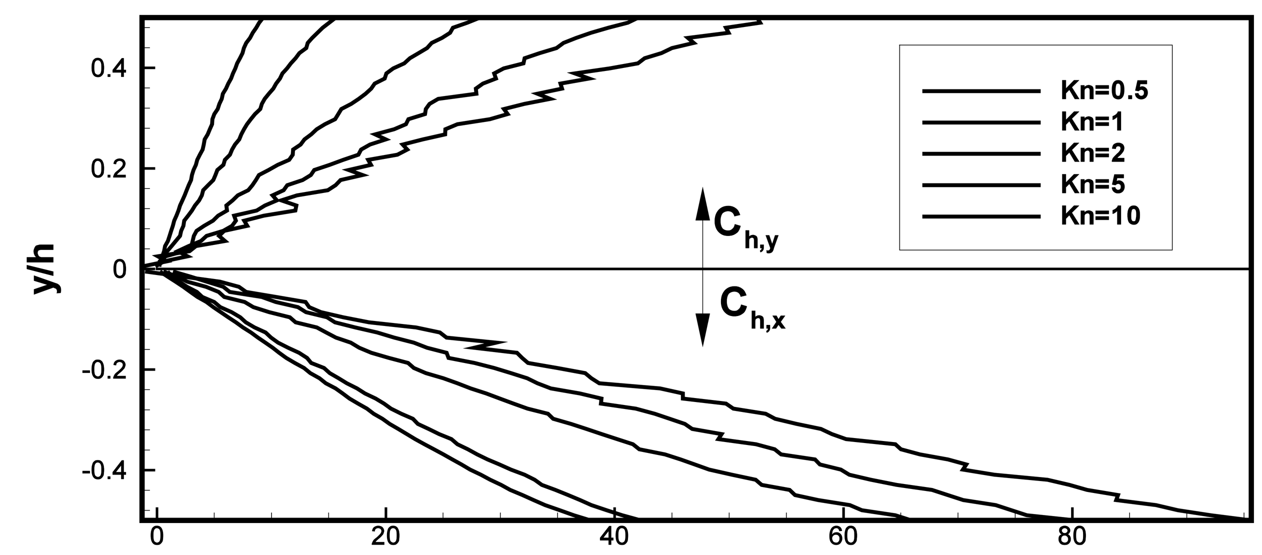

Fig.4- Rarefaction Effects on Heat Flux Profiles

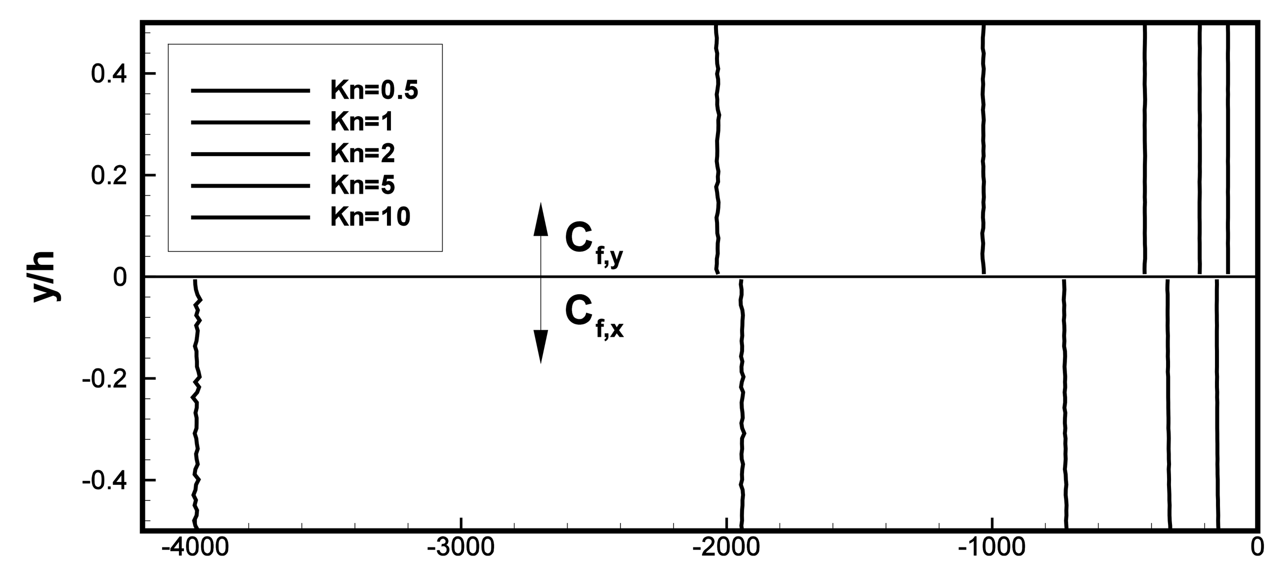

Fig.5- Rarefaction Effects on Shear Stress Profiles

Conclusion

In the present work the problem of nano-Couette flow is simulated using DSMC. The flow behavior due to variation of Knudsen number is justified and important non-equilibrium characteristics like the nonlinear velocity profiles and non-gradient transport in heat flux are shown. Also entropy as a criterion for molecular disorder is calculated using microscopic formulation. It is shown that as the flow becomes rarefied, entropy distribution tends to uniform profiles.

References

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