RESEARCH OF GAS FLOWING CHARACTERISTICS IN KNUDSEN PUMP

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Abstract: Micro Electro Mechanical System(MEMS) is a hot interdisciplinary study, with its miniaturization, low-cost mass production, highly integration, easy expansion and other advantages, which can be widely used in information, electronics, communication, military, biomedical, aerospace and other fields. Therefore, the drive and control of fluid in MEMS is one of the problems that must be solved when researching microfluidic devices. For developing and improving the microfluidic devices, micro-pumps, the drive control engine, are the most important point. The Knudsen pump was first proposed by Danish physicist Martin Knudsen in 1909. Compared to other micro-pumps, it is highly favored in the microfluidic devices application because of the advantages: no complex moving parts, simple structure, long service life, easy mass production, easy expansion, wide energy sources and low energy consumption.

Gas can flow in the channel since the gradient temperature field in the dilute gas, and the functional mechanism of the Knudsen pump is thermal induction flow. The classic Knudsen pump consists of a series of connecting fat and thin channels. Thermal creep effect is based on the gradient temperature which parallels to the wall of channel, which can drive gas flow from the low temperature to the high temperature side. In this paper, the classical Knudsen Pump in rectangular channel model is studied. We analyze the flow characteristics of single gas (Ar, N_2, O_2) respectively and mixed gas (N_2 and O_2) in the pump channels by using Direct Simulation Monte Carlo (DSMC) method based on dsmcFoam solver of OpenFOAM . In addition, how these three different molecular models (Hard-Sphere (HS) model, Variable Hard Sphere (VHS) model, and Variable Soft Sphere (VSS) model) affect the gas flow is also researched by applying self compiling code of Binary Collision Model.

The results indicate that changes in gas compositions, species, and molecular models do not affect the overall distribution and variation of the gas flow in the channels. Under the same parameters, the lighter the molecular mass is, the stronger thermal creep effect (volume flow is larger) becomes, mass flow increases with the mass of the molecules; the thermal creep effect shows a trend of increasing first and then decreasing as the increasing gas pressure, and the smaller the molecular diameter is, the greater the pressure which for the best thermal creep effect is (the smaller the Kn number is). When the proportion of the lighter molecular increases in the mixed gas, it can not only enhance the thermal creep effect but also promote the forward movement of the heavier gas. That is to say, gas with the lighter molecule mass can help the heavier one move forward. Compared with the VSS model that can more practically reflect the movement of gas, the HS model will underestimate the actual performance of the pump, while the VHS model will overestimate the actual performance. While the gas pressure is lower, the movement rule of the VSS model is more consistent with that of HS model. On the contrary, while the pressure is higher, the VSS model movement rule is closer to that of VHS model. In conclusion, the performance of thermal creep flow effect increases with the increase of the gas molecular diameter under the same condition.

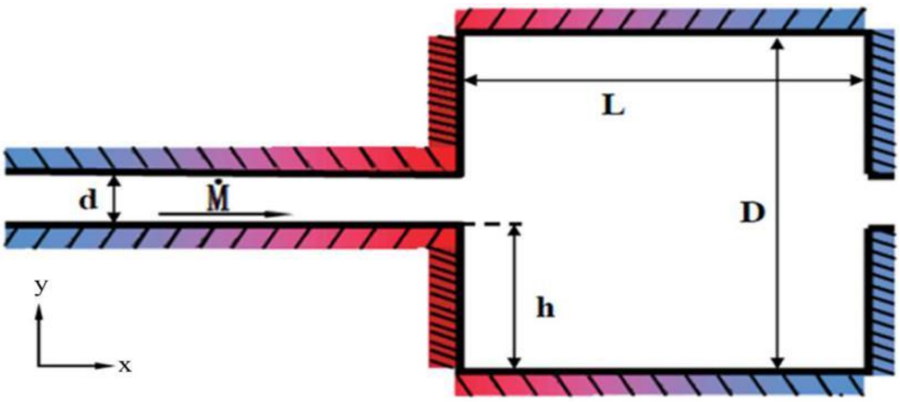

Figure 1: Knudsen pump in rectangular channel model

Table 1: Size and temperature of the model

parameter	d(um)	h(um)	L(um)	D(um)	Tc(K)	Th(K)
value	1	1	4	3	225	375

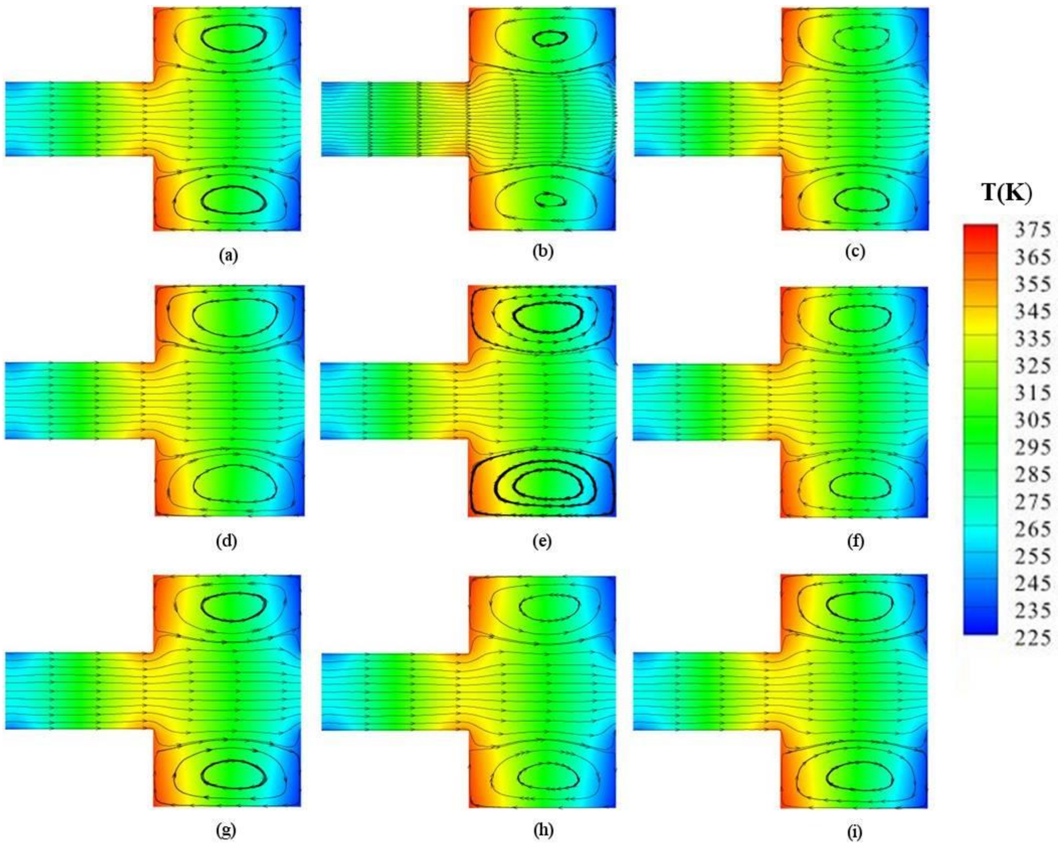

Figure 2: Streamlines and temperature contours for different gas compositions : (a)Ar; (b)N_2; (c)O_2; (d)N_2&O_2=4:1; (e)N_2&O_2=1:1; (f)N_2&O_2=1:4 and different molecular models: (g)HS model; (h)VHS model; (i)VSS model corresponding to case 1.

Table 2: Pressures for different cases

case	1	2	3	4	5	6	7	8	9
Pressure(Kpa)	101.325	71.495	35.747	14.2989	10.214	7.149	3.575	1.430	0.715

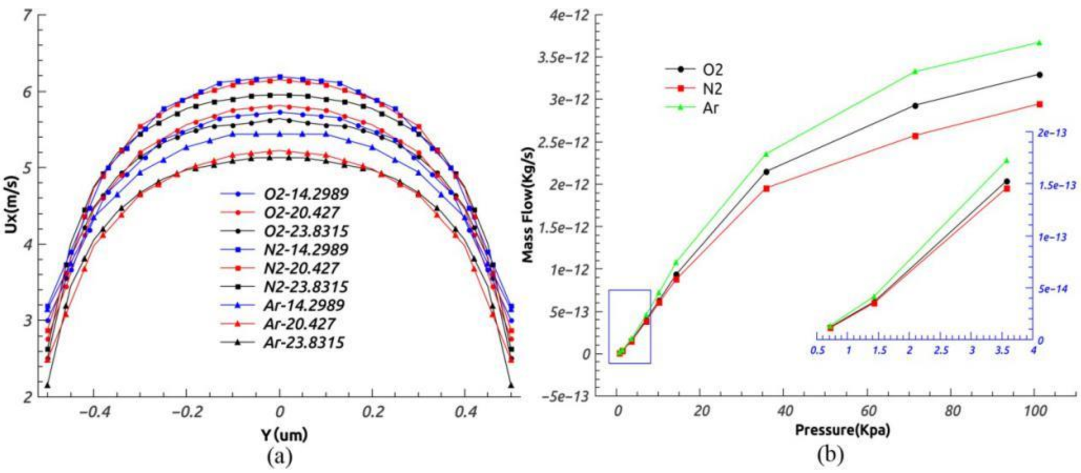

Figure 3: Under different pressures(14.2989,20.427,23.8315), (a)velocity Ux of three different gases for the reference case at X=1. (b) mass flow for three different gas at different pressures.

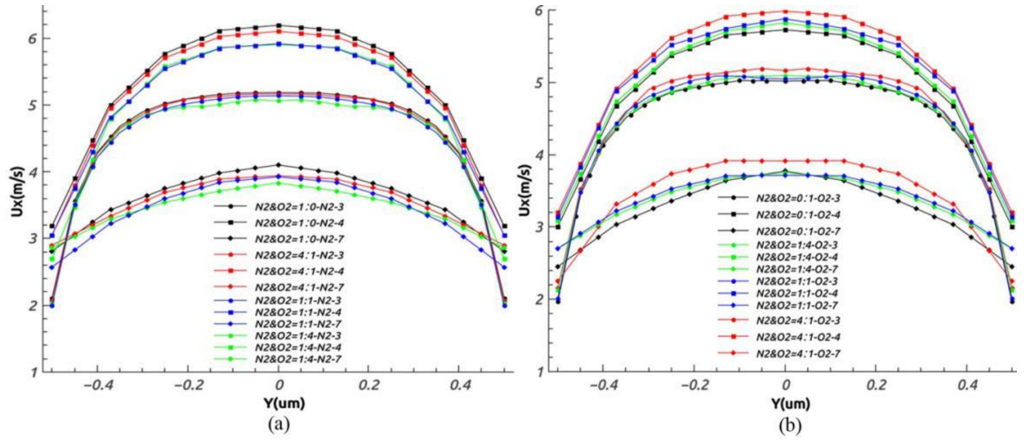

Figure 4: Velocity of three different gases for the reference case at X=1 in cases 3, 4 , and 5.

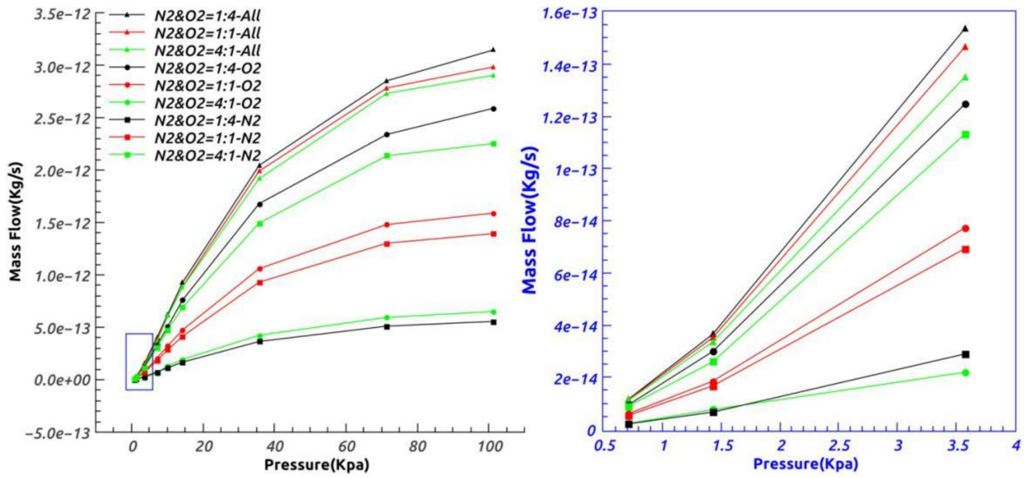

Figure 5: Mass flow and gross mass flow for three mixed gases compositions with the changes of pressure.

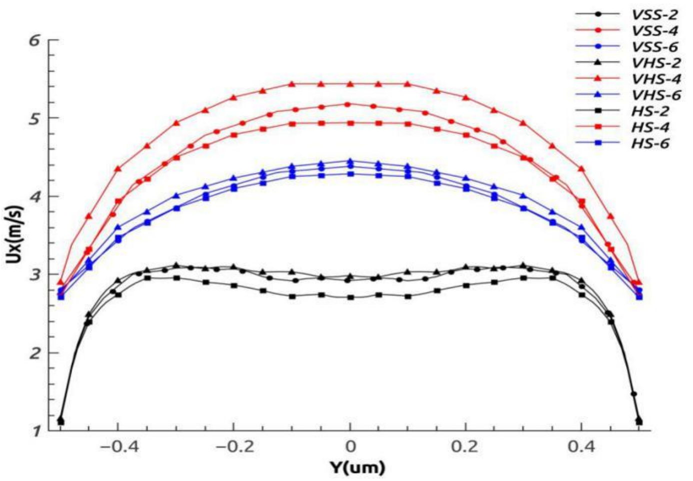

Figure 6: Velocity of three molecular models for X=1 at 2,4,6 case respectively.

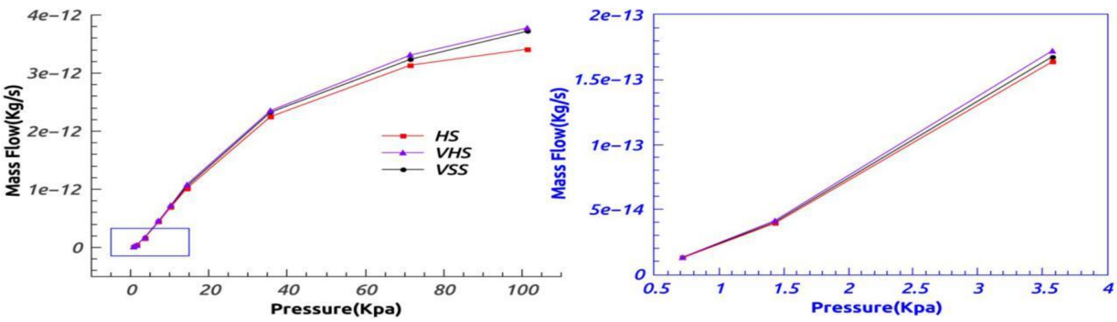

Figure 7: Mass flow changes with the the pressure for three molecular models.

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