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GASEOUS MIXTURE WITH EFFECT OF EVAPORATION AND CONDENSATION

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It is well known that during the evaporation and condensation the interface between the liquid and vapor is in non-equilibrium state. To simulate the vapor behavior in the vicinity of this liquid-vapor interface the Navier-Stokes equations with jump boundary conditions or the kinetic methods should be applied for the accurate description of the interface. The development and implementation of the kinetic approach are in a focus of interests of the present paper.

The processes of evaporation and condensation can take place for both single component and multi-component systems. For one-component gas system the adequate description of the evaporation-condensation was considered in a large number of works [1], [2], [3], [4], [5], [6], [7], namely, the case of evaporation-condensation problem between two liquid interfaces was considered in [5], [8]. However, the complete understanding of these phenomena is just far to be completely achieved. The numerical data on condensation and evaporation in gaseous mixtures, even with one condensible component, are quite fragmentary. Considerable efforts of a such investigation were made in [9], [10], but the concentration of non-condensable component was supposed to be negligibly small.

Let us consider a mixture of the monatomic gases confined between two liquid layers separated by distance H , see Fig. 1. One component (first component) of this mixture represents the gaseous fraction of the liquid phase and so can condense and evaporate. Another component (second component) of the mixture can just reflect from the surface of the liquid phase. The lower liquid interface is maintained at temperature T_1 , while the upper one is kept at temperature T_2 , $T_1 > T_2$. The molecular mass of the first (second) species is m_1 (m_2), and the corresponding number density is n_1 (n_2). We define the following governing parameters:

1. C_0 is initial equilibrium molar concentration of the condensible species,

$$C_0 = \frac{n_{01}}{n_{01} + n_{02}}, \quad (1)$$

here $n_{0\alpha}$ is the equilibrium number density of species α ($\alpha = 1, 2$). The equilibrium number density of the mixture is $n_0 = n_{01} + n_{02}$.

2. The gas rarefaction is characterized by the rarefaction parameter which is defined as

$$\delta = \frac{H}{\ell}, \quad \ell = \frac{\mu v_0}{p_0}, \quad (2)$$

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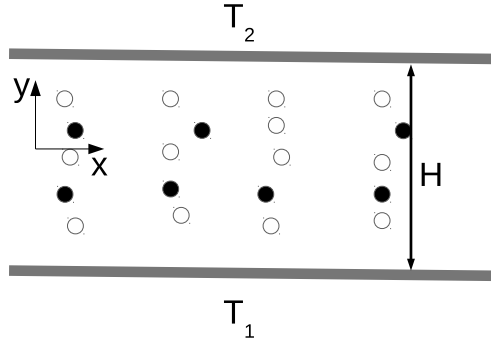


Figure 1: The geometry of the task

where ℓ is the equivalent molecular mean free path of the mixture, $\mu = \mu_1 + \mu_2$ is the viscosity of the mixture at the reference temperature T_0 , $T_0 = 0.5(T_1 + T_2)$. v_0 is the characteristic speed of the mixture defined as:

$$v_0 = \sqrt{\frac{2k_B T_0}{m}}, \quad (3)$$

where k_B is the Boltzmann constant and $m = C_0 m_1 + (1 - C_0) m_2$ is the mean molecular mass of the mixture.

We suppose that the temperature and pressure differences between the interfaces, namely $\Delta T = T_1 - T_2$ and $\Delta p = p_1 - p_2$, are small compared to corresponding equilibrium values of the temperature and pressure, T_0 and p_0 , respectively, *i.e.* $\frac{\Delta T}{T_0} \ll 1$, $\frac{\Delta p}{p_0} \ll 1$. Under this assumption of small deviation of the equilibrium state we can present the distribution function in the following form

$$f = f_0 \left(1 + h_\alpha^T \frac{\Delta T}{T_0} + h_\alpha^P \frac{\Delta p}{p_0} \right), \quad (4)$$

$h_\alpha^{T,P}$ is the perturbation of distribution function of α -component related to temperature (marked with upper index T) or pressure (index P) gradients. The McCormack model equation [11]

$$\frac{\partial h_\alpha^{(i)}}{\partial t} + \mathbf{v} \frac{\partial h_\alpha^{(i)}}{\partial \mathbf{r}} = \hat{L}_{\alpha\beta} h, \quad i = P, T \quad \alpha = 1, 2, \quad (5)$$

is used to simulate the evaporation and condensation of a gas mixture. The form of operator $\hat{L}_{\alpha\beta} h$ can be found in [12]. Equation (5) is presented in a finite-difference form and then solved numerically by discrete velocity method [13]. The calculation of the macroscopic quantities through the distribution function $h_\alpha^{P,T}$ was described in [12].

As an example, a mixture of $Ne - He$ is considered, both gases can be modeled as rigid sphere with different masses and diameters. The specific temperature range between 24K and 27.1K was chosen, where He can not be in a liquid phase while Ne can condensate and evaporate. The parameter C_0 represents the concentration of condensible Ne . The following values of masses and diameters are used in numerical simulations: $m_1 = 20.183$ u, $m_2 = 4.003$ u, $d_1 = 2.60 \cdot 10^{-10}$ m, $d_2 = 2.19 \cdot 10^{-10}$ m. The values of rarefaction parameter were equal to 0.1, 1, 10. The temperature and pressure differences were equal to 0.01 and 0.02, respectively. From Table 1 it is seen that the evaporation rate, J , decreases with increase of rarefaction parameter, while it increases with increase of the concentration of condensible component.



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δ	J		
	Ne-He		
	$C_0 = 0.1$	0.5	0.9
0.1	0.00079	0.00270	0.00394
1	0.00070	0.00254	0.00392
10	0.00032	0.00155	0.00362

Table 1: The mass flow rate, J , for various values of the concentration C_0 and the rarefaction parameter δ for mixture Ne-He, $T_1/T_2 = 1.01$, $p_1/p_2 = 1.02$

Figures 2 show the distribution of dimensionless temperature, T/T_2 , along the gap, where the distance is normalized by H . It is seen that the absolute value of a temperature slightly increases with increase of rarefaction parameter, but its dependency from the variation of the concentration looks very similar. For $C_0 = 0.1$ and 0.5 the values of the temperature are close to each other, for $C_0 = 0.9$ the temperature is slightly different, but this difference does not exceed several percents.

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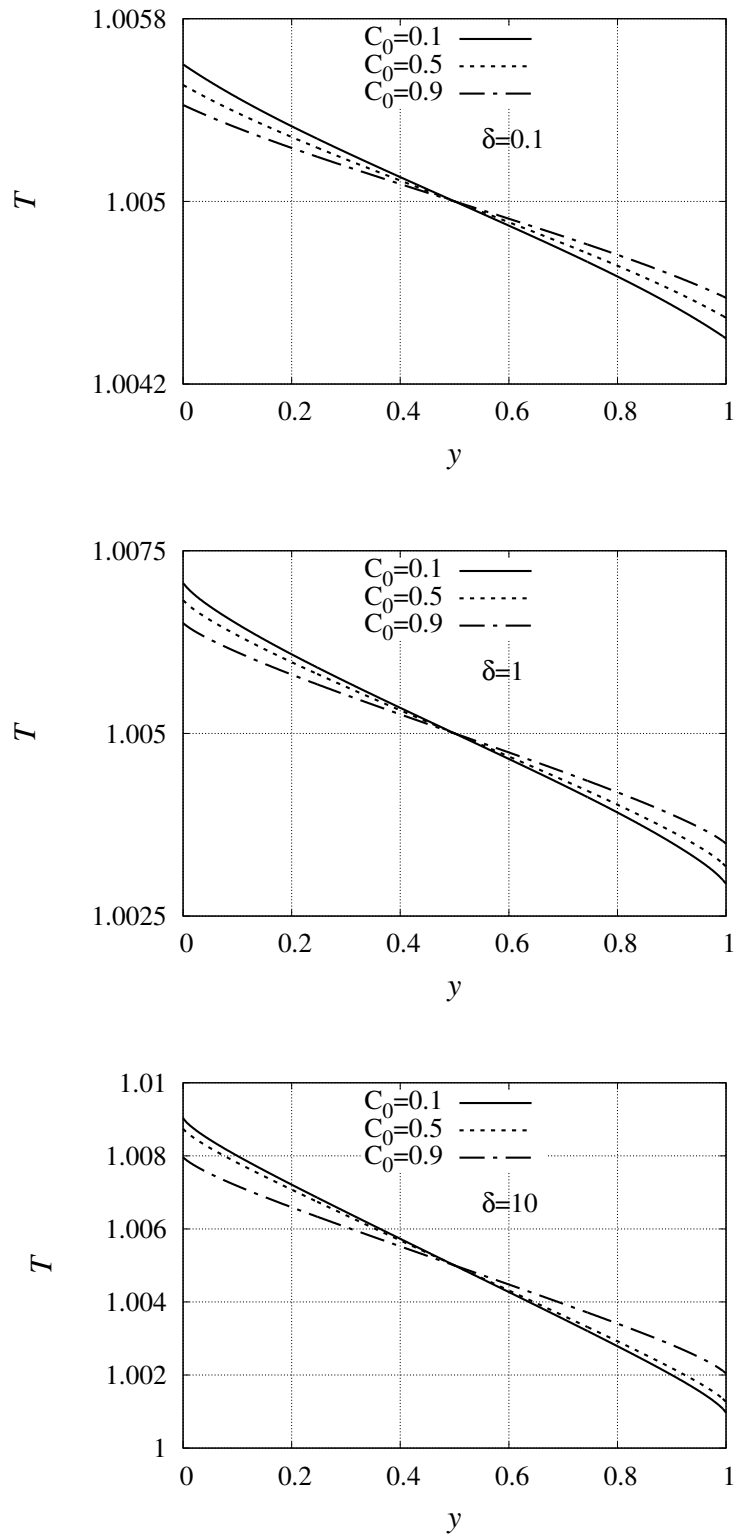


Figure 2: Temperature distribution in the gap for three values of concentration and three rarefaction levels.



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