SURFACE EFFECTS IN SHEAR STRESS ENHANCEMENT DUE TO MICRO OR NANOFLOWS AS ANALOGY FOR INCREASED RATE OF REACTION DUE TO CATALYTIC PROPERTIES IN NI_3AL

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1. Introduction

The presence of walls has naturally influence on the flow of fluid. Within the fluid layer, located in direct vicinity of the solid wall (called the wall layer), significant gradient of velocity, species and temperature are found. Together with the increase of the turbulent kinetic energy or rate of catalytic reaction, related to the Reynolds stresses and large gradients of the mean fluid velocity, the flow becomes more turbulent and the variety of different "jump" phenomena like slipping, rolling, spin-slipping, surface mobility, surface friction, thermo-porosis, etc. can occurs [1,2,3]. However, in some special applications, for example, in microfluidic and nanofluidic devices, where the surface-to-volume ratio is huge, the slip velocity behaviour obtain visible influence, and therefore a sort of "slip" hydrodynamic boundary condition should be used [4,5]. Regardless the slip physical mechanism, the degree of slip is normally quantified through the slip length, the slip velocity, the temperature jump, concentration jump, and other typical for the specific phenomena [1,2].

This work is focused on the theoretical presentation of fluid-solid interaction model with surface friction forces on of those surprising phenomena that is surface effect in shear stress enhancement due to micro or nanoflows. Some kind analogy for increased rate of reaction due to catalytic properties should be considered. As well analytical as numerical analysis can be conducted to find enhancement of mass flow rate and to find others effects important in vicinity of surface. The main assumption of this paper is that this phenomenon is completely governed by a contact interface between a solid surface and gas. Thus, from a viewpoint of mathematical modelling, the friction forces should be understood as some kind of "boundary conditions" problem. Similar consideration should be introduced into surface chemical reaction, because solid body is treated as catalyst, for example: thin foils of alloys based on intermetallic phase Ni_3Al [3].

2. Navier-Stokes boundary condition

One of the methods to model the wall layer is the use of a „wall function", which omits calculations of the viscous sublayer where the influence of the viscosity is the greatest and only half-empirically approximates the phenomena occurring between the wall and the fully turbulent layer. However, in microscale and nanoscale, there should be assumed that classical linear (laminar) models of friction forces should be enhancement by adding adherence part and non-linear (turbulent) part of friction. Therefore, the friction force possesses three known contributions: Duhem, Navier and du Buat [1,5]:

$$\mathbf{f}_r = \nu_D\,(p-\omega)\mathbf{e}_f + \nu(\mathbf{v}-\mathbf{v}_{wall}) + \nu_B(\mathbf{v}-\mathbf{v}_{wall})^2\mathbf{e}_f \tag{1}$$

where: the internal (Euler) and the external (Stokes) pressures p and ω, respectively; the slip versor is defined as: $\mathbf{e}_f = (\mathbf{v}-\mathbf{v}_{wall})/|\mathbf{v}-\mathbf{v}_{wall}|$ and ν_D, ν, ν_B are three friction coefficients [Duhem, Navier, du Buat, respectively] which are dependent simultaneously on the materials of the fluid and solid surface. The skin friction force $\mathbf{f}_r$ appearing between contacting fluid and solid materials is some additive function of powers of the slip [relative] velocity: $\mathbf{v}_s = \mathbf{v} - \mathbf{v}_{wall}$. Therefore, force of isotropic friction is a composition of three parts: the adherence dry friction, the Navier linear friction ν and the kinetic friction. However, the most important is the Navier friction force $\mathbf{f}_r = \mathbf{f}_N = \nu \mathbf{v}_s$ which is a parallel to the slip velocity $\mathbf{v}_s$. The coefficient ν is called the "external viscosity".

From mechanical point of view, the boundary conditions related to the bulk equation of fluid motion [linear momentum balance], becomes "the surface layer equation of motion". In a solid-fluid surface the separate equation of motion appears. Besides the classical 'bulk' behaviour, wall stress also appears to introduce new quantities such as surface friction force, surface mobility force, surface flux of momentum, etc. [3,4]. In the literature concerning the force boundary condition there are founded by hypothesis of Young asserts that there is no any external friction between a fluid and a solid wall then in a contacting point :

$$\boldsymbol{\tau}_{w|fluid} = \boldsymbol{\tau}_{w|solid} \tag{2}$$

Non-standard wall function is connected with the boundary condition therefore consistencies of boundary condition could be simply recognized if we compare the internal and external coefficients that appear in the model:

$$\boldsymbol{\tau}_{w|fluid} = \mathbf{p}\mathbf{n} = (\mu_0 \mathbf{I} + \mu \mathbf{d} + \mu_2 \mathbf{d}^2)\mathbf{n} = \nu_D \, (p - \omega)\mathbf{e}_f + \nu(\mathbf{v} - \mathbf{v}_{wall}) + \nu_B (\mathbf{v} - \mathbf{v}_{wall})^2 \mathbf{e}_f \, . \tag{3}$$

where: $\mathbf{d} = \frac{1}{2}(\mathrm{grad}\,\mathbf{v} + \mathrm{grad}^T\,\mathbf{v})$ - the rate of deformation, the adherence part $\mu_0 \mathbf{I}$, the Navier linear or nonlinear dynamic viscosity μ and the turbulent viscosity μ_2. Additionally, it should be mention that $\mathbf{n}$ is the unit normal vector on the boundary surface and $\mathbf{I}$ means unit tensor (Gibbs' idemfactor). The proper definition of $\boldsymbol{\tau}_{w|solid}$ is to be defined.

3. Summary

The consistency of presented model can even be extended on chemical reaction cases with enhanced properties of the solid surface for example in case on intermetallic phase Ni_3Al. The flow of a fluid mixture is characterized by an effect of concentration jump, which occurs particularly when the reacting mixture is considered, and channel walls have catalytic properties. Therefore the discontinuity of concentration may take place in the direction normal to the boundary, similar to the velocity slip. The model for the concentration boundary condition proposed by Lewis can be implemented in analogy to surface effects in shear stress enhancement due to micro or nanoflows.

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