DIMENSIONAL ANALYSIS RELATIVE TO MULTICOMPONENT MIXING AND SEPARATION PROCESSES

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A common approach to mass transfer processes in multicomponent and multiphase media from simplified point of view of mechanics is put forward. On the basis of dimensional analysis dimensionless criterial parameters are determined which enable to provide quantitative characteristics of media both in local and integral scale. The method is based on the distinction of *n-1* independent variables (so called mass moduli *MM*) in *n*-component media as mass fraction ratios of arbitrary component (*j*) to a selected basic one (*i*):

$$\frac{G_j}{G_i} = \frac{g_j}{g_i} = M_{ji}^m \tag{1}$$

The redistributions of mass fractions of individual components are introduced by differences in current and initial values of *MM*. To provide common contributions for both inert and chemically reacting media the Schwab - Zeldovich binomials are made use of. Substantial changes in media are displayed by deviation in Schwab - Zeldovich conserved parameters as the functions of differences in values of *MM*[1-2]

$$\beta_{ji} = a_i \cdot M_{i(i+j)}^m + a_j \cdot M_{j(i+j)}^m \tag{2}$$

$$\Delta\beta_{ji} = \left(a_j - a_i\right) \cdot \Delta M_{j(i+j)}^m \tag{3}$$

As the criteria on completeness of mass transport process for *n*-component media *n-1* dimensionless simplexes are derived as the degree of maximal possible deviation of Schwab - Zeldovich parameters of mutually based components

$$K_{ji} = \frac{\Delta\beta_{ji}}{\Delta\beta_{ji}^{\max}} \qquad (40$$

where K_{ji} indicates the extent of changes (similarity of mechanical „saturation”) having occurred in multicomponent media, while a special relation of K_{ji} called the conversion function

$$\Psi\left(K_{ji}\right) = \frac{K_{ji}}{1 - K_{ji}} \tag{5}$$

is proportional to mass ratio of a medium transported to a primary mass of multicomponent system. When applying the dimensional analysis in a case of negative mass increments (separation processes) it is noticeable that turning about to opposite the signs of $\Delta\beta_{ji}$ the product of K_{ji} and $\Psi(K_{ji})$ remains invariable. So introducing this product as

$$I_{ji} = \frac{\left(K_{ji}\right)^2}{1 - K_{ji}} \tag{6}$$

a certain invariant of invertibility of mass transfer processes can be termed. The quantity of I_{ji} is due to characterize periodically or randomly recurring processes. In particular, I_{ji} can be derived for the case of mass concentration fluctuations of individual components in multicomponent media. The method under consideration enables to solve the following problems: calculating the bulk mass in a downstream contour of reactive mixing shear flow; calculating the mass of separated fractions from multicomponent bulk flow; determining a local degree of mixing and its relation to reaction progress variable in reactor volume if simple chemical reaction takes place; determining an invariant to characterize the mass concentration fluctuations in turbulent multicomponent media. The nonlinear relation between K_{ji} and $\Psi(K_{ji})$ and the presence of mass density fluctuations make possible to investigate increased mixing properties in turbulent media in correlation with invariant I_{ji}.

If the current values of g_j will vary between $\left(g_j^*\right)_I$ and $\left(g_j^*\right)_{II}$ (criterion $(K_{ji})_\Sigma$ between $\left(K_{ji}\right)_I$ and $\left(K_{ji}\right)_{II}$, respectively) in volume element of turbulent medium, then invariant I_{ji} can be modified to following relation

$$I_{ji}^{'} = \frac{\left[\left(K_{ji}\right)_{II} - \left(K_{ji}\right)_I\right]^2}{\left[1-\left(K_{ji}\right)_I\right]\cdot\left[1-\left(K_{ji}\right)_{II}\right]} \tag{7}$$

Thus $I_{ji}{}'$ is responsible to such a case of process when alternatively the direct and inverted changes of mass fraction from $\left(g_j^*\right)_I$ to $\left(g_j^*\right)_{II}$ take place. This pattern of phenomenon, if carried over to fluctuations in mass density, will give an opportunity for quantitative evaluation of these fluctuations of mass concentration in turbulent core of medium[3].

Below the solution of two exemplary problems from chemical and power engineering are presented to illustrate some applications of the method under consideration. The preliminary assumptions on subject are taken as follows: reacting media are admitted to be continuous one of fluid or pulverized dispersion of solid in fluid; the summary effect of a chemical reaction can be modelled by the run of simple reaction of the type $A + B \to C$ (simple chemically reacting system SCRS); the effective mechanism of a process is regarded as the confluence and mixing of reactive media jointly with a simultaneous finite rate chemical reaction.

Problem I. To determine a local degree of mixing (mixedness) χ in the volume of flow reactor while both the mixing and the simple reaction $A + B \to C$ are simultaneously to take place at finite rates. The solution of the problem is unfeasible in conventional way as in the case of mixing of nonreacting components of A and B by determination the local mass fraction of incoming component B:

$$\chi = \frac{g_B}{(g_B)_{id}} \tag{8}$$

On the basis of dimensional analysis method a degree of mixing can be expressed as a ratio of criteria

$$\chi = \frac{K_{BA}}{(K_{BA})_{id}} \tag{9}$$

The rate of χ between the states of complete segregation and ideal mixing of components A and B is obtained on the basis of differences in reactive scalar parameters β_{BA} in conformity to pattern when component B penetrates into the mass of component A. The effective formula is given by

$$\chi = \frac{\eta}{\eta + \Delta\beta_{BA}} \tag{10}$$

where η is a reaction progress variable (reactedness) and

$$\Delta\beta_{BA} = \frac{(g_B)_{id}}{\left(M_{BA}^m\right)_{real}} - (g_A)_{id}\cdot\eta \tag{11}$$

$\left(M_{BA}^{m}\right)_{real}$ is to be determined as the actual ratio concerning all elemental fractions of A and B in reactive medium.

Problem II. To determine the mass of entrained medium in downstream contour of burning jet when the simple reaction of combustion $A + B \rightarrow C$ takes place at finite rate in the flame. Conventional way for solution consists in measurements of velocity field in separate cross sections of jet flow jointly with local specification of fluid density and successive summation of local mass fluxes over the relevant cross section of the flow. Using the dimensional analysis method the measurement either of the flow velocity or its temperature is not obligatory within downstream contour of the flame. It is sufficient to fix the distribution of substantial parameters such as mass fractions of components in the volume of the flame with a view to provide the set of values of the function $\Psi(K_{BA})$ in volume elements in that volume. Then, on the basis of averaged over separate cross sections values of $\Psi(K_{ji})$ after integration along the axis of the flame, the total excessive mass of entrained medium can be found by following governing equations (the concept of stream tube with permeable walls):

$$M_{\Sigma'\Sigma}^{m} = \int_0^x \left(q_F^m \cdot \int_F \Psi(K_{BA}) \cdot dF \right) \cdot dx \qquad (12)$$

$$q_F^m = q_{0F}^m \cdot \frac{F_0}{F} \qquad (13)$$

where q_{0F} denotes initial mass flux averaged over initial cross section of the flow, F_0 and F are equal to initial and current areas of cross sections, respectively.

The method was approbated by the calculation of the mass of recirculating gases and entrained excess air, as well as the mass of gasified fuel in the confined pulverized oil shale flame in an inverted combustion chamber[4].

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