TWO PHASE MIXTURE FILTRATION

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ABSTRACT: *This study describes new theory about filtrating of two-phase mixture passing through porous media. As a base of the two-fluid model of the two-phase flow and accepting the porous material as a media with increased resistance. The mathematical model is numerically solved using the appropriate descretization method. Some preliminary results from the numerical solution are presented – gas and admixture velocities distribution in longitudinal direction as a function of filtrating layer thickness.*

Keywords: *Two-phase mixture, porous media, filtrating layer.*

1. INTRODUCTION

The two fluid model of the two phase flow is based on Landau's hypothesis about possibility of existence in one volume of liquefied helium and gas possessing the property hyper-conductivity. The idea was applied and accepted by Nigmatulin[1] for multiphase flows. According two fluid model theory two phase mixture is compound of two fluids – of the carrying media and the admixture phase. Each of those two fluids has their own velocity, density and temperature in each point of the continuum covered by the flow. The admixture phase is treated as particular fluid media where continuity equation is accepted. In order to be applied the phenomenological methods for description and research of the admixture it is necessary to be accepted that solid phase represents incompact great number of particles. It means that the relaxation time after the stroke between particles is always lower than two consecutive strokes:

$$\tau_p < \tau_y \qquad (1)$$

The above accepted condition excludes from the model accelerated interaction between admixture particles, and recovering of their quantity movement at the expense of carrying media. This simplification leads to the following two limitations about accepted for the admixtures fluid media:

- It does not possess the tensor of the inside stresses and,
- The Ideal gas flow (Clapeyron's equation) here could not be applied.

The first limitation means that pressure and viscous stresses are missing. However the admixture phase possesses the tensor of the turbulent stresses, respectively it has own turbulence because the turbulence is not a flow characteristic but of its behavior.

The filtrating porous material is well presented in Idelchik[2] as media with increased resistance. The resistance of a curtain media could be calculated using the well known relation for calculation of minor losses.

$$\Delta p_{ЗМС} = \zeta.\rho\frac{u_m^2}{2} \quad (2)$$

where: $\rho\frac{u_m^2}{2}$ is dynamic pressure; ζ - loss coefficient – here function of material type, material arrangement, thickness of the layer and etc.

Much more difficult could be establish the relation of the resistance for the second phase (admixture). There are two basics parameters defining the characteristics of the phase: mass (or volume) concentration χ (α) and diameter (size of the particles accepted for the sphere) D_p. It is necessary here to be applied the correction functions giving the degree of resistance which will increasing after the admixture phase passing through the filtrating material. Since the correction functions here are necessary to be dimensionless the impact of the diameter of the particles (D_p) have to be expressed by Reynolds number in relation to the admixture phase:

$$\mathrm{Re}_p = \frac{\left(V_p - V_g\right)}{\upsilon} D_p \quad (3)$$

For all parameters here with subscript "g" are noted the gas phase parameters, and with "p" – the admixture phase parameters.

The Reynolds number (Re_p) also shows the impact of the relative velocity between two phases - $\left(V_p - V_g\right)$, and also the viscosity υ of the carrying media.

The loss coefficient of the porous media layer after passing the solid media could be expressed as follow:

$$\zeta_p = \zeta_g.f(\chi).f\left(\mathrm{Re}_p\right) \quad (4)$$

or based on the volume concentration α :

$$\zeta_p = \zeta_g.f(\alpha).f\left(\mathrm{Re}_p\right) \quad (5)$$

where $f(\chi)$, $f(\alpha)$ and $f\left(\mathrm{Re}_p\right)$ are correction functions giving the impact of the respect parameters.

The polynomial expression here is proposed for function $f\left(\mathrm{Re}_p\right)$ commonly used for porous layer resistance calculations.

$$f\left(\mathrm{Re}_p\right) = a_0 + a_1 \mathrm{Re}_p^{1/2} + a_2 \mathrm{Re}_p + a_3 \mathrm{Re}_p^{3/2} + \ldots \quad (6)$$

According [3] for the friction drag coefficient of the spherical particle the following values for the independent parameters could be accepted as $a_0 = 1$, $a_1 = 0,179$, $a_2 = 0,013$, $a_3 = a_4 = ... = 0$. Therefore for $f\left(\mathrm{Re}_p\right)$ we have the expression:

$$f\left(\mathrm{Re}_p\right) = 1 + 0,179\mathrm{Re}_p^{1/2} + 0,013\mathrm{Re}_p \quad (7)$$

Referring to the mass concentration χ the following expressions have been recommended:

– With taking into consideration the initial mass concentration χ_0:

$$f(\chi) = (1+\chi_0)^{3/2} \quad (8a)$$

– With taking into account the maximum for the given section mass concentration χ_m:

$$f(\chi) = (1+\chi_m)^{3/2} \quad (8b)$$

According [4] the relation between χ and α is given with:

$$\alpha = \frac{\chi\rho_g}{\rho_p} \quad (9)$$

For function $f(\alpha)$ could be written the expressions:

$$f(\alpha) = \left(1+\frac{\alpha\rho_{p0}}{\rho_{g0}}\right)^{3/2} \quad (10a)$$

$$f(\alpha) = \left(1+\frac{\alpha\rho_{pm}}{\rho_{gm}}\right)^{3/2} \quad (10b)$$

Loss coefficient is defining according [2] for the respective type concentration of the porous (filtrating) media. As an example for the media compounds of spherical particles with diameter $d_з$ and angle (θ) between the axes of three spherical particles, the loss coefficient (ζ_g) could be expressed with:

$$\zeta_g = kh_o \quad (11)$$

where: h_o is layer thickness, k - resistance coefficient for unit of thickness:

$$k \approx \frac{k'\lambda'}{d_з} \quad (12)$$

where: $k' = \frac{1,53}{\varepsilon'^{4,2}}$,

$$\lambda' = \frac{30}{\text{Re}} + \frac{3}{\text{Re}^{0,7}} + 0,3 \quad (13)$$

In relations (13) Re and ε' are given with:

$$\text{Re} = \frac{0,45}{(1-\varepsilon').\sqrt{\varepsilon'}}.\frac{w_g.d_з}{\upsilon_p};$$

$$\varepsilon' = 1 - \frac{\pi}{\theta.(1-\cos(\theta)).\sqrt{1+2.\cos(\theta)}} \quad (14)$$

The proposed correction functions $(7 \div 10)$ could be specified in presence of complete experimental information of similar two phase flows.

Additional terms to the porous media model

Two very important characteristics of the porous media are the coefficients m and η. They are characteristics of porous area and volume. The following expressions could be written:

$$m = \frac{W_\eta}{W} \text{ and } \eta = \frac{S_\eta}{S} \quad (15)$$

where: W_η is volume occupied by the pores; W - total volume of the filtrating material; S_η - area of the pore (porous area); S - total cross section.

However the porous area coefficient does not give the complete information for the media. In a curtain level it could be used to be calculated the average size of the pores (perforations) in porous material.

Single porous area could be defined as follow:

$$f_{1m} = \frac{f_{св.с}}{k} \quad (16)$$

where $f_{св.с} = f_{\Sigma}$, $f_{св.с}$ and f_{Σ} are the respective areas occupied by the pores in a given cross section and total area of the porous material, k - number of perforations, f_{1m} - average area of single pore.

With average area f_{1m} could be defined the reduced diameter of the pore:

$$d_r = 1{,}128\sqrt{f_{1m}} \quad (17)$$

With the average reduced diameter of the pore in porous material is defining the first additional condition when the problem has a solution:

$$d_r < D_p, \quad (18)$$

or to be avoided any kind of uncertainty for relation (17) could also be accepted:

$$D_p \le k_d d_r \quad (19)$$

where k_d uncertainty factor that the particle could pass through the porous media without to be kept on the entrance level.

The solid particles going through the porous media are kept from the filtrating material, and deposited. Over the time the characteristics of the media have been changed, and its porosity decreasing as a result of pore slogging. As a result the resistance coefficient has been increased over the time.

The flow rate could be calculated as number of particles to be multiplied by their volume in the porous material:

$$Q_p = NW_p \quad (20)$$

where: number of particles is: $N = \frac{G_{p_0}}{\rho_p W_p}$, G_{p_0} - mass rate is identified with incoming mass for unit time; $W_p = \frac{3}{4}\pi D_p^3$. N - is number of particles for unit time.

The time needed for filling-up the given volume from the porous media is calculating as follow:

$$t = \frac{k_\pi . W_{cp}}{N.W_p} \quad (21)$$

Proportionally with filling-up the unoccupied volume, in porous media is expecting to increase the loss coefficient as well as the resistance coefficient with respect of the carrying media and the admixture phase media.

Considering gradually filling-up of the pores in the media could be inserted one additional correction factor with respect of ζ_g :

$$\zeta_g(t) = k_1(t)\zeta_{g_0} \quad (22)$$

where: ζ_{g_0} is initial value of the loss coefficient for the gas phase and $k_1(t)$ - correction coefficient considering the filling-up of the unoccupied media in porous material:

$$k_1(t) = \frac{k_n W_{cp}}{k_n W_{cp} - NW_p t} \quad (23)$$

As well as the loss coefficient of the admixture phase ζ_p is derivative of ζ_g the last one will increase when ζ_p increasing.

Expression (23) fearlessly could be used as a control parameter. It will show the time when the filter should be changed because it is a function of volume filling-up with admixtures over the time. The function $k_1(t)$ changes from 1 to ∞. When $k_1(t) > 4$ which corresponds to volume filling-up more than 75% is necessary the filter to be washed or changed.

2. MATHEMATICAL MODEL

Two phase stationary turbulent flow passing over porous media is describing with Euler's type equations concerning the resistance media. Two-fluid scheme of the flow here is accepted. It is accepted also that two-phase flow reaching porous media as a two separate jets either with flat or symmetric initial cross section. In order to be used one system differential equation for both phases an index "j" here is accepted. With $j=0$ the system is referring to the flat jet flows, and by $j=1$ is valid for axisymmetric spreading. Here are presented the basic equations describing the flow:

$$\frac{\partial u_g}{\partial x} + \frac{1}{y^j}\frac{\partial\left(v_g y^j\right)}{\partial y} = 0 \qquad (24)$$

$$\frac{\partial u_p}{\partial x} + \frac{1}{y^j}\frac{\partial\left(v_p y^j\right)}{\partial y} = 0 \qquad (25)$$

$$\left(1+\zeta_g\right)\left(\rho_g u_g \frac{\partial u_g}{\partial x} + \rho_g v_g \frac{\partial u_g}{\partial y}\right) = \frac{\partial p}{\partial x} - \frac{1}{y^j}\frac{\partial}{\partial y}\left(y^j \rho_g \overline{u'_g v'_g}\right) - F_x \qquad (26)$$

$$\frac{\partial p}{\partial y} = -F_y \qquad (27)$$

$$\left(1+\zeta_p\right)\left(\rho_p u_p \frac{\partial u_p}{\partial x} + \rho_p v_p \frac{\partial u_p}{\partial y}\right) = -\frac{1}{y^j}\frac{\partial}{\partial y}\left(y^j \rho_p \overline{u'_p v'_p}\right) + F_x \qquad (28)$$

It is necessary to be added the equation giving the transfer of the mass concentration χ:

$$\rho_g u_p \frac{\partial \chi}{\partial x} + \rho_g v_p \frac{\partial \chi}{\partial y} = -\frac{1}{y^j}\frac{\partial}{\partial y}\left(y^j \rho_g \overline{v'_p \rho'_p}\right) \qquad (29)$$

Eq. $(26) \div (28)$ include the inter-phase interaction forces F_x and F_y. According the accepted two fluid model in the equations referring to the gas phase $(26) \div (27)$ it has negative value (-), and for the admixture phase – with positive value (+).

This shows that the quantity loss of the admixture phase as a result of inter-phase interaction forces is compensated on the base of carrying media. In current case the following inter-phase forces are also recommending to be included:

– x-direction (forces F_x) – aerodynamic force (F_A) could be defined with the expression:

$$F_A = C_R s \rho_g \frac{u_r^2}{2} \quad (30)$$

where air resistance coefficient C_R is defining as a function only of Re_p: $C_R = f\left(\mathrm{Re}_p\right)$; s - average cross section of the particle; $u_r = u_g - u_p$ - relative velocity in horizontal direction.

The second force in x direction is gravity force (appearing from the particle weight). It could be referred to the inter-phase interaction forces because it has no influence directly over movement of the carrying media. It is written in the admixture phase equation Eq. (28) and it is defining as:

$$F_g = \pm m_p g \quad (31)$$

In horizontal direction the most significant impact has the Safmen's force because it is a function of transverse gradient of the velocity of the carrying media:

$$f_S = k_S \upsilon \rho_g D_p \left(u_g - u_p\right)\sqrt{\frac{\partial u_g}{\partial y}} \quad (32)$$

where: $k_s = C_s/4 = 1.61,\ C_s = 6.46$

Eq. (32) is valid when

$$u_s / \sqrt{\nu \frac{\partial u_g}{\partial y}} << 1\ ,\ \mathrm{Re}_p << 1$$

The Magnus's force here would give lower impact under flow development because of the media structure – the rotation of the particles here would be decreased. In case of presence of additional temperature or electrostatic fields the additional forces have to be included:

- Thermophoresy force:

$$f_T = -4{,}5\upsilon^2\left(\frac{\rho_g}{T_g}\right)\frac{D_p \lambda_g}{\left(2\lambda_g + \lambda_p\right)}\nabla T_g \quad (33)$$

- Electrophoresis force:

$$f_E = \left(\frac{\pi}{6}\right)\rho_p D_p^3 q E$$

The thermophoresy force mentioned in Eq. (33) is a result of temperature difference between two phases. The heat transfer is called inter-phase and leads to temperature change of both phases. Those changes are noted with the expressions:

$$\rho_g\left[U_g \frac{\partial \overline{T_g'}^2}{\partial x} + V_g \frac{\partial \overline{T_g'}^2}{\partial y}\right] = \frac{1}{y^j}\frac{\partial}{\partial y}\left[y^j \rho_g\left(\frac{\upsilon_{tg}}{\sigma_T}\right)\partial \overline{T_g'}^2\right] + \rho_g\left[-2\overline{V_g' T_g'}\frac{\partial T_g}{\partial y} - \frac{1}{R'}\left(\frac{\varepsilon_g}{k_g}\overline{T_g'}^2\right)\right] - \theta_p \quad (34)$$

$$\rho_p\left[U_p \frac{\partial \overline{T_p'}^2}{\partial x} + V_p \frac{\partial \overline{T_p'}^2}{\partial y}\right] = \frac{1}{y^j}\frac{\partial}{\partial y}\left[y^j \rho_p\left(\frac{\upsilon_{tp}}{\sigma_T}\right)\partial \overline{T_p'}^2\right] + \rho_p\left[-2\overline{V_p' T_p'}\frac{\partial T_p}{\partial y} - \frac{1}{R'}\left(\frac{\varepsilon_p}{k_p}\overline{T_p'}^2\right)\right] - \theta_p^* \quad (35)$$

Where R' is the ratio of temperature to the dynamic time scale; $(\theta_p,\ \theta_p^*)$ are the thermal turbulent components of the two-phase flow.

3. TURBULENT STRESSES MODELING

Three parametric model of turbulence [4] [5] [6] - $k_g - k_p - \varepsilon$ here is used in order to be modeled the turbulent stresses. With this model the above mentioned two-fluid scheme of the flow is complete. For the turbulent energy of both phases are written two separate transport equations. It is accepted one general equation about energy dissipation ε. It is also possible to be applied four parametric model of turbulence completely described in [7] - $k_g - k_p - \varepsilon_g - \varepsilon_p$. However this will complicate the problem with minimal increasing of the precision. The modeling equations of three parameter model of turbulence have the expressions:

$$(y^j \rho_g U_g).\frac{\partial k_g}{\partial x} + (y^j \rho_g V_g).\frac{\partial k_g}{\partial y} = \frac{\partial}{\partial y}\left[\frac{y^j \rho_g \upsilon_{tg}}{\sigma_k}.\frac{\partial\left(k_g + \frac{\chi_o}{1+\chi_o} k_p\right)}{\partial y}\right] + y^j \rho_g \upsilon_{tg}.\left[\frac{\partial U_g}{\partial y}\right]^2 - y^j \rho_g (\varepsilon + \varepsilon_p) \quad (36)$$

$$(y^j \rho_p U_p).\frac{\partial k_p}{\partial x} + (y^j \rho_p V_p).\frac{\partial k_p}{\partial y} = \frac{\partial}{\partial y}\left[\frac{y^j \rho_p \upsilon_{tp}}{\sigma_k}.\frac{\partial\left(k_p + \frac{\chi_o}{1+\chi_o} k_g\right)}{\partial y}\right] + y^j \rho_p \upsilon_{tp}.\left[\frac{\partial U_p}{\partial y}\right]^2 - y^j \rho_p \varepsilon_p^* \quad (37)$$

$$(y^j \rho_g U_g).\frac{\partial \varepsilon}{\partial x} + (y^j \rho_g V_g).\frac{\partial \varepsilon}{\partial y} = \frac{\partial}{\partial y}\left[\frac{y^j \rho_g \upsilon_{tg}}{\sigma_\varepsilon}.\frac{\partial\left(\varepsilon + \frac{\chi_o}{1+\chi_o}.k_p k_g\right)}{\partial y}\right] - y^j \rho_g \Phi_p \quad (38)$$
$$+ C_{\varepsilon 1} y^j \rho_g \frac{\varepsilon}{k_g}\left[\upsilon_{tg}.\left(\frac{\partial U_g}{\partial y}\right)^2 + G\right] - y^j \rho_g.\frac{\varepsilon^2}{k_g}.\left(C_{\varepsilon 2} - C_{\varepsilon 3}.\chi\right)$$

The turbulent viscosities presented in Eq. (37) and (38) are defining with the expressions:

$$\upsilon_{tg} = -\rho_g \overline{u'_g v'_g} = C_\upsilon \frac{k_g^2}{\varepsilon} \quad (39)$$

$$\upsilon_{tp} = -\rho_p \overline{u'_p v'_p} = C_\upsilon \frac{k_p^2}{\varepsilon} \quad (40)$$

The double correlation expression presented in Eq. (29) is defining with:

$$\overline{v'_p \rho'_p} = -D_p \frac{\partial \overline{\rho}_p}{\partial y} \quad (41)$$

The following model equations for inter-phase heat transfer are accepted:

$$Q_{gt} = c_{pg} \rho_g \overline{T'_g V'_g} R_j.2\pi$$

And

$$Q_{p1} = c_{pp}.\rho_p.\left(T_2 - T_p\right).V_p.R_j 2.\pi \quad (42)$$

$$Q_{g1} = c_{pg}.\rho_g.\left(T_2 - T_g\right).V_g.R_j 2.\pi$$

And

$$Q_{pt} = c_{pp} \rho_p \overline{T'_p V'_p} R_j.2\pi \quad (43)$$

The turbulent correlations directly referred to the temperature are defining with:

$$\overline{T'_g V'_g} = -\frac{\upsilon_{tg}}{\Pr_t}\frac{\partial T_g}{\partial y} \quad (44)$$

$$\overline{T'_p V'_p} = -\frac{\upsilon_{tp}}{\Pr_t}\frac{\partial T_p}{\partial y} \quad (45)$$

The constants in model equations are given in Table 1.

The value of $C_\mu = 0,09$ is based on numerical experiment for the flow where the generation (P) and turbulent dissipation energy are equal.

Table 1

C_μ	$C_{1\varepsilon}$	$C_{2\varepsilon}$	$C_{3\varepsilon}$	σ_K	σ_ε
0,09	1,44	1,92	0,8	1,0	1,3

Table 2

Z	A	B	C	D
$\overline{\chi}$	$\overline{y}.\overline{U}_p$	$\overline{y}.\overline{V}_p - \frac{\partial}{\partial \overline{y}}\left(\overline{y}.\frac{\overline{\upsilon}_{tp}}{Sc_t}\right)$	$\overline{y}.\frac{\overline{\upsilon}_{tp}}{Sc_t}$	$-\overline{\chi}.\frac{\partial}{\partial \overline{y}}\left(\overline{y}.\overline{V}_p\right)$ $-\overline{y}.\overline{\rho}_p\frac{\partial \overline{U}_p}{\partial \overline{x}}$
$\overline{U}_g$	$\overline{y}.\overline{\rho}_g.\overline{U}_g.$ $.\left(1+\zeta_g\right)$	$\left(1+\zeta_g\right)\overline{y}.\overline{\rho}_g.\overline{V}_g -$ $-\frac{\partial}{\partial \overline{y}}\left(\overline{y}.\overline{\rho}_g.\overline{\upsilon}_{tg}\right)$	$\overline{y}.\overline{\rho}_g.\overline{\upsilon}_{tg}$	$-\overline{y}.\overline{F}_x$
$\overline{U}_p$	$\overline{y}.\overline{\rho}_p.\overline{U}_p$ $.\left(1+\zeta_p\right)$	$\left(1+\zeta_p\right)\overline{y}.\overline{\rho}_p.\overline{V}_p -$ $-\frac{\partial}{\partial \overline{y}}\left(\overline{y}.\overline{\rho}_p.\overline{\upsilon}_{tp}\right)$ $-\overline{y}.\frac{\overline{\upsilon}_{tp}}{Sc_t}.\frac{\partial \overline{\rho}_p}{\partial \overline{y}}$	$\overline{y}.\overline{\rho}_p.\overline{\upsilon}_{tp}$	$\overline{y}.\overline{F}_x$
$\overline{T}_g$	$\frac{\overline{y}.\overline{\rho}_g.\overline{U}_g.\overline{C}_{pg}}{R}$	$\frac{\overline{y}.\overline{\rho}_g.\overline{U}_g.\overline{C}_{pg}}{R} -$ $-\frac{\partial}{\partial \overline{y}}\left[\overline{y}.\overline{\rho}_g.\frac{\overline{C}_{pg}.\overline{\upsilon}_{tg}}{R.\Pr_t}\right]$	$\overline{y}.\overline{\rho}_g.\frac{\overline{C}_{pg}.\overline{\upsilon}_{tg}}{R.\Pr_t}$	$-\overline{y}.\overline{Q}+\overline{F}_x.\overline{y}.\left(\overline{U}_g-\overline{U}_p\right)+$ $+\overline{F}_y.\overline{y}.\left(\overline{V}_g-\overline{V}_p\right)$ $+2.\pi.R_j.\overline{\rho}_g.\left(T_2-\overline{T}_g\right).\overline{V}_g$ $-2.\pi.R_j.\overline{\rho}_g.\frac{\overline{\upsilon}_{tg}}{\Pr_t}.\frac{\partial \overline{T}_g}{\partial \overline{y}}$

$\bar T_p$	$\frac{\bar y.\bar\rho_p.\bar U_p.\bar C_{pp}}{R}$	$\frac{\bar y.\bar\rho_p.\bar U_p.\bar C_{pp}}{R} - \frac{\partial}{\partial\bar y}\left[\bar y.\bar\rho_p.\frac{\bar C_{pp}.\bar\upsilon_{tp}}{R.\Pr_t}\right] - \bar y.\frac{\bar C_{pp}.\bar\upsilon_{tp}}{R.Sc_t}\frac{\partial\bar\rho_p}{\partial\bar y}$	$\bar y.\bar\rho_p.\frac{\bar C_{pp}.\bar\upsilon_{tp}}{R.\Pr_t}$	$\bar y.\bar Q + 2.\pi.R_j.\bar\rho_p.\left(T_2-\bar T_p\right).\bar V_p - 2.\pi.R_j.\bar\rho_p.\frac{\bar\upsilon_{tp}}{\Pr_t}.\frac{\partial\bar T_p}{\partial\bar y}$
$\bar k_g$	$\bar y.\bar\rho_g.\bar U_g$	$\bar y.\bar\rho_g.\bar V_g - \frac{\partial}{\partial\bar y}\left(\bar y.\bar\rho_g.\frac{\bar\upsilon_{tg}}{\sigma_k}\right)$	$\bar y.\bar\rho_g\frac{\bar\upsilon_{tg}+\frac{\chi_0}{1+\chi_0}.\bar\upsilon_{tp}}{\sigma_k}$	$\bar y.\bar\rho_g.\bar\upsilon_{tg}.\left(\frac{\partial\bar U_g}{\partial\bar y}\right)^2 - \bar y.\bar\rho_g.\left(\bar\varepsilon+\bar\varepsilon_p\right)$
$\bar k_p$	$\bar y.\bar\rho_p.\bar U_p$	$\bar y.\bar\rho_p.\bar V_p - \frac{\partial}{\partial\bar y}\left(\bar y.\bar\rho_p.\frac{\bar\upsilon_{tp}}{\sigma_k}\right)$	$\bar y.\bar\rho_p\frac{\bar\upsilon_{tp}+\frac{1}{1+\chi_0}.\bar\upsilon_{tg}}{\sigma_k}$	$\bar y.\bar\rho_p.\bar\upsilon_{tp}.\left(\frac{\partial\bar U_p}{\partial\bar y}\right)^2 - \bar y.\bar\rho_g.\bar\varepsilon_p^*$
$\bar\varepsilon$	$\bar y.\bar\rho_g.\bar U_g$	$\bar y.\bar\rho_g.\bar V_g - \frac{\partial}{\partial\bar y}\left(\bar y.\bar\rho_g.\frac{\bar\upsilon_{tg}}{\sigma_\varepsilon}\right)$	$\bar y.\bar\rho_g.\frac{\bar\upsilon_{tg}}{\sigma_\varepsilon}$	$\frac{C_{\varepsilon1}.\bar y.\bar\rho_g.\bar\varepsilon}{\bar k_g}\bar\upsilon_{tg}.\left(\frac{\partial\bar U_g}{\partial\bar y}\right)^2 + \frac{C_{\varepsilon1}.\bar y.\bar\rho_g.\bar\varepsilon}{\bar k_g}\bar\upsilon_{tg}G - \bar\rho_g.\bar y.\bar\Phi_p - \frac{\bar\rho_g.\bar y.\bar\varepsilon^2.(C_{\varepsilon2}-C_{\varepsilon3})}{\bar k_g}.$

4. NUMERICAL MODELING OF THE FLOW

The equations (26), (28), (29), (36)$\div$(38), (42), (43) could be presented as one general (characteristic) equation:

$$A.\frac{\partial\bar Z}{\partial\bar x} + B.\frac{\partial\bar Z}{\partial\bar y} = C.\frac{\partial^2\bar Z}{\partial\bar y^2} + D \qquad (46)$$

where Z, A, B, C, D are reduced variables and parameters with meanings shown in Table 2.

5. NUMERICAL SOLUTION RESULTS

The presented mathematical model, which describes the filtration process of two-phase mixture is numerically solved by using the appropriate Duffort-Frankel discretization scheme. The scheme of discretization is described in detail in [8].

The results from numerical solution present information about distribution of some basic parameters of two-phase flow in the filtration process. The thickness of the filtration material is one of the basics parameters defining the distribution of the velocity components of two phases, turbulent energies, degree of jet expansion and etc.

In this current work, some important results from the numerical solution are presented. The main purpose is to demonstrate the distribution of some basic parameters of the flow in the process of filtration, and for which the experimental data in the literature are missing.

Numerical solution was performed with the following initial conditions:

- *Velocities of both phases:* $U_{g0} = U_{p0} = 5,\ 10$ и $20\ m/s$;
- *Particle diameter:* $D_p = 100;\ 200\ \mu m$.
- *Thickness of the filtration material*: $h_0 = 50 \div 250\ mm$

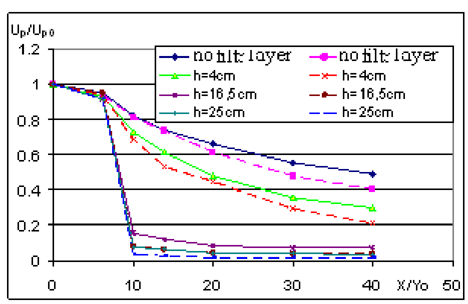
It is focused on the longitudinal velocity components distribution of both phases. The velocities behavior is the most important factor for the filtration process effectiveness.

In *Fig. 1a* is shown the decreasing of the maximum dimensionless velocity component of the admixture at the lowest filtrating velocity ($U_{g0} = U_{p0} = 5m/s$) with different thicknesses of the filtrating material. The velocity distribution is given for both types of particle diameter. Friction coefficient of the filtrating layer is accepted to be $\zeta = 10.8$ according [2]. In the figure with continuous line is presented the admixture phase velocity distribution with particle's diameter $D_p = 100\mu m$, and broken line shows the velocity distribution for the particles with diameter $D_p = 200\mu m$.

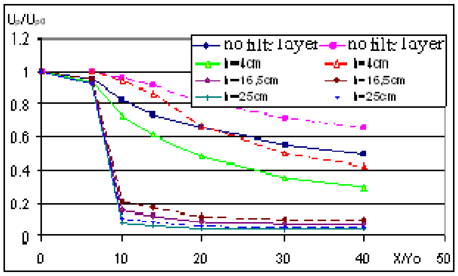
It is obvious that the admixture phase velocity decreases faster at greater particle diameter for all thicknesses of the filtrating layer. For the current case (at the chosen initial parameters of the flow) the effective value of the layer thickness is expected to be $h = 16,5cm$. At this layer thickness could be accepted that admixture velocity is tended to be zero which is the indicator for "holding" of the particles from the layer.

If the filtrating layer thickness is higher than the "holding", from the figure is obvious that velocity profile is not changing significantly which means that increasing of the thickness above the "holding" does not influence under filtration process.

In *Fig. 1b* is presented another numerical solution for the velocity distribution but this time at different initial velocities $U_{g0} = U_{p0} = 5$ and $10m/s$. The broken lines on the figure are referred to the higher initial velocity. Also here should be noticed that the velocity profiles are significantly differ before reaching the "holding" layer thickness. After that the profile stays relatively stable.



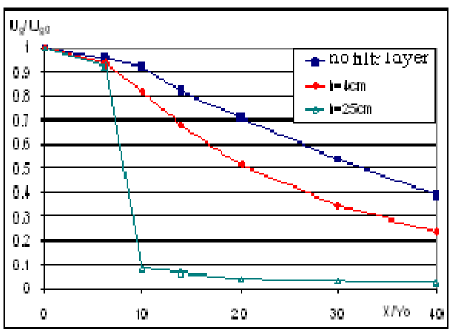
(a)



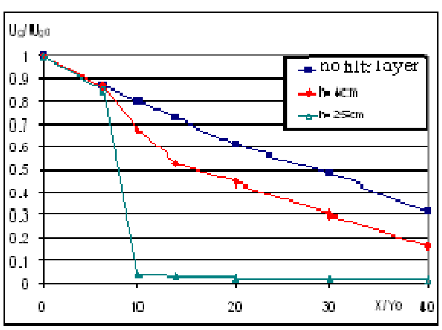
(b)

Figure 1. Velocity admixture distribution a) when $D_p = 100\mu m$; $D_p = 200\mu m$ b) when $U_{g0} = U_{p0} = 5$ and $10 m/s$

In *Fig. 2a* is presented the dimensionless gas phase velocity distribution for the smaller diameter of the particles ($D_p = 100\mu m$).



(a)



(b)

Figure 2. Gas phase velocity distribution a) at $D_p = 100\mu m$ b) at $D_p = 200\mu m$

The three regimes are reviewed here – without filtrating layer, and with thickness of the layer respectively $h = 4$ and $25cm$. In *Fig. 2b* is presented the same case but the diameter of the particles is $D_p = 200\mu m$. The initial velocities for both cases are $U_{g0} = U_{p0} = 5m/s$. From both figures could be noted that velocity distribution in accordance with the *Fig. 1* is higher at higher admixture diameter. The decreasing of the admixture phase velocity is lower than the gas phase.

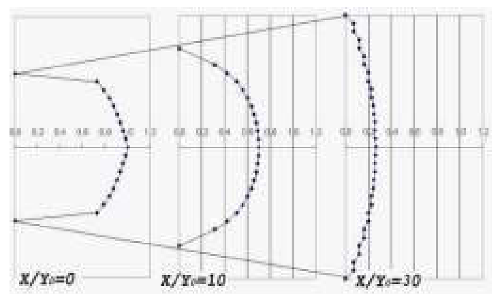


Figure 3. Velocity profiles of the gas phase

Fig. 3 shows the gas phase velocity profiles (in the same case of *Fig. 2b*) for three different cross sections of the two phase flow at lowest thickness of the filtrating layer. From the figure is obvious that the velocity for the cross section $X/Y_0 = 30$ is approximately 5 times lower that the initial velocity – this is because of the presence of the filtrating layer.

6. CONCLUSION

In the work, we present the complete mathematical model of two-phase filtrating flow special attention was paid on the defining the parameters influencing of the filtrating layer characteristics.

The mathematical model is numerically solved using the appropriate descretization method. Some preliminary results from the numerical solution are presented, which include gas and admixture velocities distribution in longitudinal direction as a function of filtrating layer thickness.

MÔ PHỎNG QUÁ TRÌNH LỌC HỖN HỢP DÒNG HAI PHA

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TÓM TẮT: *Bài báo trình bày một mô hình mới mô phỏng quá trình lọc hỗn hợp dòng hai pha chảy qua lớp vật liệu xốp trên cơ sở mô hình hai pha độc lập và sự gia tăng trở lực của lớp vật liệu xốp. Lời giải số được thực hiện thông qua mô hình sai phân thích hợp. Kết quả tính toán cho ta biểu đồ liên hệ giữa phân bố vận tốc của các pha với chiều dày lớp lọc dọc theo trục dòng phun.*

Từ khóa: dòng hai pha, vật liệu xốp, trục dòng phun.

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