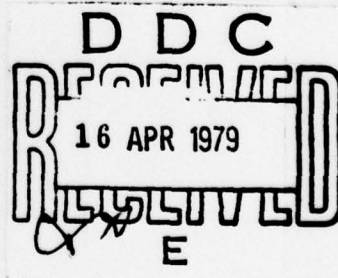FTD-ID(RS)T-1846-78

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FOREIGN TECHNOLOGY DIVISION

INVESTIGATION OF THE TURBULENT FLOW OF
MULTICOMPONENT FLUSHING FLUID
BETWEEN TWO PARALLEL PLATES

by

R.M. Khasayev, A.K. Mamedov, A.T. Abbasov

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ë in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

i

Investigation of the Turbulent Flow of
Multicomponent Flushing Fluid
Between Two Parallel Plates

R. M. Khasayev, A. K. Mamedov, A. T. Abbasov

As investigations have shown in recent years [1], the structured flow of
drilling flushing fluids and cement mortars is described by a viscoplastic model.
However, in a turbulent motion mode, the structured viscosity and the critical
shear stress becomes insufficient for the flow characteristics of multicomponent
fluids.

According to [2], in a turbulent motion mode the effect of the viscous pro-
perties decreases, and the effect of the solid components in the fluid has a
predominant influence on its motion. In accordance with the theory of the
motion of fluids in a boundary layer the viscous properties are preserved near
the walls and as the flow core is approached their effect disappears [3].

In connection with this, when calculating the turbulent flow of drilling
flushing fluids, cement mortars and other multicomponent fluids it is advisable
to break the fluid flow down into three areas:

1.

1) into a a structured sublayer, where the motion is determined mainly by the viscous forces and by the forces of the critical shear stress;

2) into a turbulent transition layer, described by a Newtonian model with turbulent viscosity;

3) into a turbulently moving core, where the effect of viscosity is negligibly small.

On the basis of the accepted model the laws of the variation of friction stress can be represented accordingly for each area:

$$\tau_i = \begin{cases} \tau_0 - \tau_i \dfrac{\partial v_1}{\partial y}; & i = 1; \quad 0 < y < \delta_i; \\[2mm] \tau_{ii} \dfrac{\partial v_2}{\partial y}; & i = 2; \quad \delta_i < y < (\delta_i + \delta_i); \\[2mm] \rho l^2 \left(\dfrac{\partial v_3}{\partial y}\right)^2; & i = 3; \quad (\delta_i + \delta_i) < y < \dfrac{h}{2}. \end{cases}$$

In accordance with the accepted laws of variation in friction stress and in accordance with [1,3] let us take the velocity distributions in the individual areas of motion:

$$\left. \begin{aligned} v_1 &= -\frac{\Delta p}{2l\tau_i} y^2 + c_1 y_i + c_2; & 0 \leqslant y < \delta_i; \\[2mm] v_2 &= 8.57 v_* \left[\frac{v_*(y - \delta_i)}{\tau_{ii}}\right]^{\frac{1}{7}} + c_3; & \delta_i < y \leqslant (\delta_i + \delta_i); \\[2mm] v_3 &= 2.5 v_* \ln\left(\frac{y}{\delta_i + \delta_i}\right) + c_1; & (\delta_i + \delta_i) < y < \frac{h}{2}. \end{aligned} \right\} \quad (1)$$

As the boundary conditions for the determination of the unknown constants of integration let us take

2.

$$v_1(0) = 0; \quad v_1(\delta_{\scriptscriptstyle A}) = v_2(\delta_{\scriptscriptstyle A});$$

$$v_2(\delta_{\scriptscriptstyle A} + \delta_{\scriptscriptstyle T}) = v_3(\delta_{\scriptscriptstyle A} + \delta_{\scriptscriptstyle T});$$

$$v_3\left(\frac{h}{2}\right) = v_{\text{макс}};$$

$$\tau_0 - \eta \frac{\partial v_1}{\partial y}\bigg|_{y=\delta_{\scriptscriptstyle A}} = \frac{\Delta p(h - 2\delta_{\scriptscriptstyle A})}{2l};$$

$$\tau_0 - \eta \frac{\partial v_1}{\partial y}\bigg|_{y=\delta_{\scriptscriptstyle A}} + \tau_{\scriptscriptstyle T}\frac{\partial v_2}{\partial y}\bigg|_{y=\delta_{\scriptscriptstyle A}+\delta_{\scriptscriptstyle T}} = \frac{\Delta p \delta_{\scriptscriptstyle T}}{l};$$

$$\rho l^2 \left(\frac{\partial v}{\partial y}\right)^2\bigg|_{y=\delta_{\scriptscriptstyle A}+\delta_{\scriptscriptstyle T}} = \frac{\Delta p[h - 2(\delta_{\scriptscriptstyle A}+\delta_{\scriptscriptstyle T})]}{2l}.$$

(2)

where v_1, τ_1; $v_2\tau_2$; $v_3\tau_3$ are the averaged velocities and friction stresses respectively in each area; h is the distance between the plates; $\delta_{\scriptscriptstyle A}$, $\delta_{\scriptscriptstyle T}$ are the thicknesses of the structured boundary layer and the turbulent sublayer; η, $\eta_{\scriptscriptstyle T}$ are the structured and turbulent viscosity of the fluid; τ_0 is the critical shear stress; v_*, v_*' are the dynamic velocity respectively for the transition turbulent sublayer and the turbulent core; ρ is the density of the fluid; l is the value which expresses the approximate law of the fractionation of the law (sic) [Translator's note: probably should be - flow] into layers with similar distributions of relative averaged velocities.

Employing the conditions of (2) from equation (1) let us compile the following equations:

$$-\frac{\Delta p}{2l\eta}0 + c_1 0 + c_2 = 0;$$

$$-\frac{\Delta p}{2l\eta}\delta_{\scriptscriptstyle A}^2 + c_1\delta_{\scriptscriptstyle A} = c_3;$$

$$8.57 v_* \left[\frac{\rho v_* \delta_{\scriptscriptstyle T}}{\eta_{\scriptscriptstyle T}}\right]^{\frac{1}{7}} + c_3 = c_4;$$

$$v_{\text{макс}} = 2.5 v_*' \ln \frac{h}{2(\delta_{\scriptscriptstyle A}+\delta_{\scriptscriptstyle T})} + c_4;$$

$$\tau_0 - \eta \frac{\Delta p}{l\eta}\delta_{\scriptscriptstyle A} - \eta c_1 = \frac{\Delta p(h - \delta_{\scriptscriptstyle A})}{2l}$$

(3)

3.

From joint solution (3) we will have:

$$c_1 = \frac{\tau_0}{\eta_i} - \frac{\Delta p \delta_\pi}{l \eta_i} - \frac{\Delta p (h - \delta_\pi)}{2 l \eta_i}; \quad c_2 = 0;$$

$$c_3 = \frac{\tau_0 \delta_\pi}{\eta_i} - \frac{\Delta p \delta_\pi^2}{l \eta_i} - \frac{\Delta p h \delta_\pi}{2 l \eta_i};$$

$$c_4 = 8{,}57 v_* \left[\frac{\rho v_* \delta_\tau}{\eta_{it}} \right]^{\frac{1}{7}} + \frac{\tau_0 \delta_\pi}{\eta_i} - \frac{\Delta p \delta_\pi^2}{l \eta_i} - \frac{\Delta p h \delta_\pi}{2 l \eta_i};$$

$$v_{\text{макс}} = 8{,}57 v_* \left[\frac{\rho v_* \delta_\tau}{\eta_{it}} \right]^{\frac{1}{7}} + 2{,}5 v_* \ln \frac{h}{2(\delta_\pi + \delta_\tau)} +$$

$$+ \frac{\tau_0 \delta_\pi}{\eta_i} - \frac{\Delta p \delta_\pi^2}{l \eta_i} - \frac{\Delta p h \delta_\pi}{2 l \eta_i}.$$

$$(4)$$

Having substituted the values c_1, c_2, c_3, c_4 and $v_{\text{макс}}$ from (4) in (2) we will have:

$$v_1 = -\frac{\Delta p y^2}{2 l \eta_i} + \left(\frac{\tau_0}{\eta_i} - \frac{\Delta p \delta}{2 l \eta_i} - \frac{\Delta p h}{2 l \eta_i} \right) y;$$

$$v_2 = 8{,}57 v_* \left[\frac{\rho v_* (y - \delta_\pi)}{\eta_{it}} \right]^{\frac{1}{7}} + \frac{\tau_0 \delta_\pi}{\eta_i} - \frac{\Delta p \delta_\pi^2}{l \eta_i} - \frac{\Delta p h \delta_\pi}{2 l \eta_i};$$

$$v_3 = 2{,}5 v_* \ln \left(\frac{y}{\delta_\pi + \delta_\tau} \right) + 8{,}57 v_* \left[\frac{\rho v_* \delta_\tau}{\eta_{it}} \right]^{\frac{1}{7}} + \frac{\tau_0 \delta_\pi}{\eta_i} - \frac{\Delta p \delta_\pi^2}{l \eta_i} - \frac{\Delta p h \delta_\pi}{2 l \eta_i}.$$

$$(5)$$

Let us determine th flow rate of the multicomponent fluid between the two parallel plates

$$Q = 2 \int_0^{\delta_\pi} v_1 \, dy + 2 \int_{\delta_\pi}^{\delta_\pi + \delta_\tau} v_2 \, dy + 2 \int_{\delta_\pi + \delta_\tau}^{\frac{h}{2}} v_3 \, dy \qquad (6)$$

Substituting the values v_1, v_2 and v_3 from (5) in (6), we will have:

$$Q = -\frac{\Delta p}{2 l \eta_i} \int_0^{\delta_\pi} y^2 \, dy + \left(\frac{\tau_0}{\eta_i} - \frac{\Delta p \delta_\pi}{2 l \eta_i} - \frac{\Delta p h}{2 l \eta_i} \right) \int_0^{\delta_\pi} y \, dy +$$

$$+ 8{,}57 \left[\frac{\rho v_*}{\eta_\tau} \right] \int_{\delta_\tau}^{\delta_\pi + \delta_\tau} (y - \delta_\pi) \, dy + \left(\frac{\tau_0 \delta_\pi}{\eta_i} - \frac{\Delta p \delta_\pi^2}{l \eta_i} - \frac{\Delta p h \delta_\pi}{2 l \eta_i} \right) \int_{\delta_\pi}^{\delta_\pi + \delta_\tau} dy +$$

$$+ 2{,}5 v_* \int_{\delta_\pi + \delta_\tau}^{\frac{h}{2}} \ln \frac{y}{\delta_\pi + \delta_\tau} \, dy + \left[8{,}57 v_* \left(\frac{\rho \delta_* \delta_\tau}{\eta_{it}} \right)^{\frac{1}{7}} + \frac{\tau_0 \delta_\pi}{\eta_i} - \frac{\Delta p \delta_\pi^2}{l \eta_i} - \frac{\Delta p h \delta_\pi}{2 l \eta_i} \right] \int_{\delta_\pi + \delta_\tau}^{\frac{h}{2}} dy.$$

4.

After carrying out integration and the appropriate transformations for the flow rate of the fluid we will obtain the expression:

$$Q = \frac{(3\tau_0 l - \Delta p h - 6\Delta p \delta_s^2)\delta_s^2 + (6\tau_0 l - 3\Delta p h)\delta_s \delta_\tau - 4\Delta p \delta_\tau^2}{3l\eta_i} +$$
$$+ 5v_* \left[\frac{h}{2}\left(\ln \frac{|h}{2(\delta_s + \delta_\tau)} - 1 \right) + \delta_s + \delta_\tau \right] + 15 v_* \delta_\tau \sqrt[7]{\frac{\rho v_* \delta_\tau}{\eta_{i\tau}}} +$$
$$+ \left(8,57 v_* \sqrt[7]{\frac{\rho v_* \delta_\tau}{\eta_{i\tau}}} + \frac{2\tau_0 l \delta_s - 2\Delta p \delta_s^2 - \Delta p h \delta_s}{2l\eta_i} \right) |h - 2(\delta_s + \delta_\tau)| \tag{7}$$

In equation (7) δ_s and δ_τ, are also unknowns, which can be determined from the following equations, compiled in accordance with the conditions of (2):

$$\delta_s = h - \frac{2,45 l \eta_{i\tau} v_*}{\Delta p} \cdot \left(\frac{\rho v_*}{\eta_\tau} \right)^{\frac{1}{7}} \delta_\tau^{-\frac{6}{7}} + 2\delta_\tau;$$

$$\delta_s + \delta_\tau = \frac{h}{6} + \left\{ \frac{h^3}{216} - \frac{3,06\rho l^3 (v_*')^2}{\Delta p} + \left[\left(\frac{h^3}{216} - \frac{3,06\rho l^3 (v_*')^2}{\Delta p} \right)^2 - \right. \right.$$
$$\left. \left. - \frac{125 h^6}{105,97} \right]^{\frac{1}{2}} \right\}^{\frac{1}{3}} + \left\{ \frac{h^3}{216} - \frac{3,09\rho l^3 (v_*')^2}{\Delta p} + \left[\left(\frac{h^3}{216} - \right. \right. \right.$$
$$\left. \left. \left. - \frac{3,06 l^3 (v_*')^2}{\Delta p} \right)^2 - \frac{125 h^6}{105.97} \right]^{\frac{1}{2}} \right\}^{\frac{1}{3}}, \tag{8}$$

where

$$v_* = \left[\frac{2 l \tau_0 (\eta_i - 1) + \Delta p (3\delta_s + h)}{2 \rho l \eta_i} \right]^{\frac{1}{2}};$$

$$v_*' = \left\{ \frac{[2 l \tau_0 (\eta_i - 1) + \Delta p (3\delta_s + h)](\delta_s + \delta_\tau)^2}{12,5\rho l^3 \eta_i} \right\}^{\frac{1}{2}}.$$

Equations (7) and (8) make it possible in the determination of the flow rate of the multicomponent fluid during its turbulent motion to take into account the effect of the viscoplastic properties of the fluids (η, τ_0) and the concentration of the solid particles (η_τ) in it.

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