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ABSTRACT

[illegible]

1. Introduction

[illegible]

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[illegible]:10.1016/[illegible].2010.12.007

2. Experimental setup and procedure

2.1. Fracture models

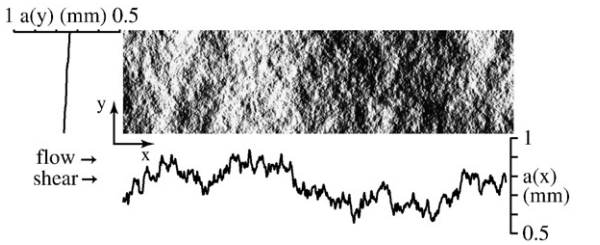


Fig. 1. T : ca a "ba ": = 1 , b ac = 0.5 . Ma : 1360 b 360 . B : fi a $a(x)=<a(x,y)>_y$ a $w=90$; fi a $a(y)=<a(x,y)>_x$ $L=350$.

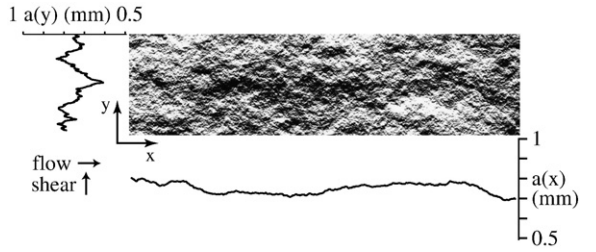


Fig. 2. T – ca a "c a ": T a , c a a b a F . 2.

W c a a fl (a , , x), a ac a ca (F . 2): a , ca a "c a " . I a F . 2, , a , a a b a a . T "c a " a a $a(y)=\langle a(x,y)\rangle_x$ y (c), $a(x)=\langle a(x,y)\rangle_y$ c x (b c).

2.2. Experimental set up and fluids

T ac ca (F . 3). T ca (ac a a b fl) a a (–). T ( ) c c a c ac T a ( ) afl ba c a b a a: a fl c a a . T ac a a b a R C a HQ CCD ca a a a (B c a ., 2009).

F c ca a , a (90 20 1 ^{3}) a c a HP 4284A a a a a qc 1 H T a qc c a ac (a) c a

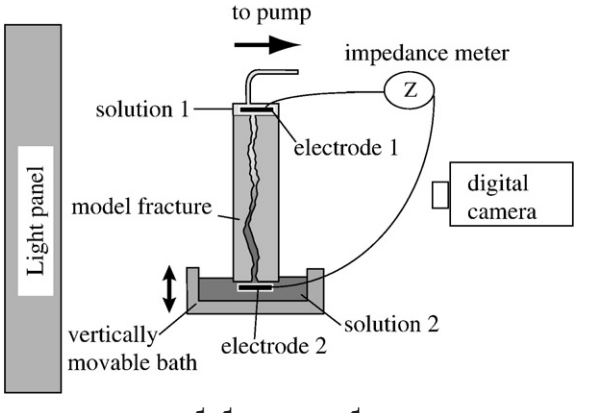


Fig. 3. Sc a c a .

c a) . T c a a a c a . T fl N -N a a (1000) a . T ca c a ac c a c b B c a a . (2009). O fl 0.3 / A B (H b a K a , 2002) c a a a NaC (a a fr a b a c a). T a b a c ab b a c a a a a c a b c ca c c a a . F c a c c , a d ( ) a s (a). T c c c a a : $\sigma_s=2.27$ S/c a $\sigma_d=2$ S/c .

P a b c - a . F , a c , a ac ca fl (B c a ., 2009): ac fl c b c a ab a . M , a fl c , : a b a c ab a c a .

2.3. Experimental procedure for displacement experiments

I a fl ba b ac a d ac a s. W , fl ab a d a s T c a a a ac ca a a a . L a - a (B c a ., 2009). T a fl c U a b 0.0024 a 0.24 / (2.8<*Pe*<285 c b *Pe* fi b $Pe=U\langle a(x,y)\rangle_{x,y}/D_m$.

T a a ac c , b ac a c a ab a a , a a a a , a c c a .

I ca d a b s, a c ac a d ( ) a c a b s.

T a a a b c c c a b D b (a , 2008). I , b c c $\sigma_s=0.227$ S/ , a : $a\sigma_s=1.710^{-4}$ S ($a=0.75$ a). A , a a 10^{-9}S c c (R a G , 1998), fi a D b 10^{-4}. T , , c b a ac c a ac a ca b c .

2.4. Fracture resistance for full saturation with one or other solution

[illegible] (Table 1).

[illegible] R_s/R_d [illegible] Table 1 [illegible] 2% [illegible]:

$$\frac{R_s}{R_d} = \frac{\rho_s}{\rho_d} = 0.82 \pm 0.02. \quad (1)$$

[illegible] $R_{channel}/R_{barrier}$ [illegible]:

$$\frac{R_{channel}}{R_{barrier}} = 0.85 \pm 0.03. \quad (2)$$

[illegible] $<a(x,y)>_{x,y} = 0.75$ [illegible]. $R_s^{pp} = L/(wa\sigma_s) = 22.8\,k\Omega$ [illegible] $R_d^{pp} = L/(wa\sigma_d) = 26\,k\Omega$ [illegible] Sec. 2.2).

[illegible] R/R^{pp} [illegible] Table 1: [illegible] 10% [illegible].

[illegible] σ_d. [illegible] R^* [illegible]:

$$R^* = \frac{R - R_d}{R_s - R_d}, \quad (3)$$

[illegible]

$$R^* = \frac{R - R_s}{R_d - R_s}, \quad (4)$$

Table 1
R_s, R_d, R_s/R_d: [illegible] R/R^{pp}: [illegible].

	$R_s(k\Omega)$		$R_d(k\Omega)$		R_s/R_d		R/R^{pp}	
[illegible]	25.5	0.2	30.5	0.2	0.83	0.01	1.15	0.03
[illegible]	21.5	0.2	26.5	0.2	0.81	0.01	0.98	0.04

[illegible] R^* [illegible] $t = Ut/L$ [illegible] $t^* = Ut/L$ ([illegible] U [illegible] L [illegible]). [illegible] $t^* = 1$ [illegible].

3. Displacement experiments: results

3.1. Channel geometry

[illegible] R^* [illegible] t^* [illegible] $t^* \simeq 0.7$ (Fig. 4). [illegible] $t^* \geq 0.7$, [illegible] R^* [illegible] t^* [illegible] 1. [illegible] ($t^* = 1$) [illegible]. [illegible] R^* [illegible] t^* [illegible] Pe. [illegible] ($R^* = 0$) [illegible] Pe [illegible] ([illegible] $t^* \sim 1.5 - 1.7$).

3.2. Barrier geometry

[illegible] ([illegible] $R^* = 1$) [illegible] $t^* = 1$ [illegible] (Fig. 5). [illegible].

[illegible] dR^*/dt^* [illegible] $0 < t^* < 0.5$ [illegible] $0.5 < t^* < 0.8$ [illegible] Fig. 5). [illegible] t^* [illegible]

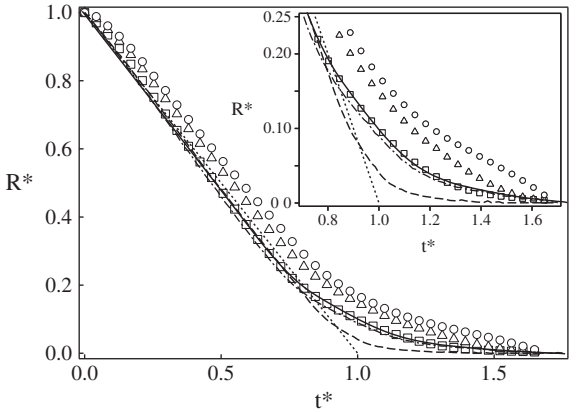


Fig. 4. [illegible] R (Eq. (3)) [illegible] $t = Ut/L$ [illegible]. ○: $Pe = 28$, (△): $Pe = 142$, (□): $Pe = 285$. [illegible] Sec. 4.2 $n = 0.26$; [illegible] $n = 1$. [illegible].

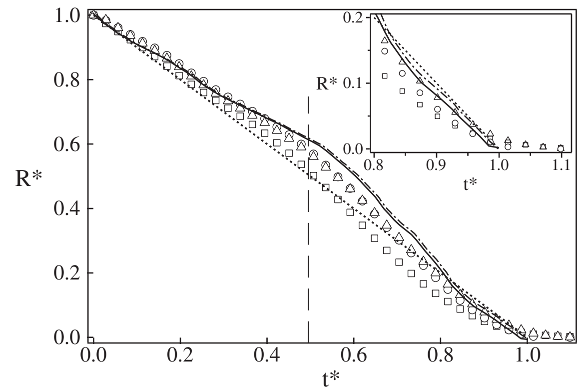


Fig. 5. [illegible] R [illegible] $t=Ut/L$ [illegible] Fig. 4. D [illegible] (Eq. (10)), [illegible] Section 4.3. [illegible] t [illegible] $R(t)$ [illegible]

[illegible] $Pe=285$.

[illegible] R^* [illegible] t^* [illegible]

4. Displacement experiments: models

[illegible]

4.1. Parallel plates geometry

[illegible] (Bacri et al., 2003; Taylor, 1953). [illegible] c_d [illegible] d [illegible]:

$$c_d(\zeta) = \frac{1}{2}(1 \pm Erf(\zeta)); \tag{5}$$

[illegible] $\zeta = (x - Ut)/\left(2\sqrt{Dt}\right)$, x [illegible], U [illegible], t [illegible] D [illegible] d [illegible] s).

[illegible] $\rho(x,y,t)$ [illegible] y [illegible]

[illegible] L [illegible]:

$$R(t) = \frac{1}{aw}\int_0^L \rho(x,t)dx, \tag{6}$$

[illegible] $\rho(x,y,t) = \rho(x,t)$ [illegible] c_d [illegible] d [illegible]: $1/\rho(x,t) = c_d(x,t)\sigma_d + (1 - c_d(x,t))\sigma_s$. Eq. (6) [illegible]:

$$R(t) = \frac{1}{\sigma_s aw}\int_0^L \frac{1}{1-\chi c_d(x,t)}dx, \tag{7}$$

[illegible] $\chi = 1 - \sigma_d/\sigma_s$. [illegible] σ_s [illegible] σ_d, [illegible] $\chi c_d \ll 1$. Eq. (7) [illegible]:

$$R(t) \simeq \frac{1}{\sigma_s aw}\left(L + \chi\int_0^L c_d(x,t)dx\right). \tag{8}$$

[illegible] d [illegible] aw [illegible] s, [illegible] Qt/aw [illegible] Q [illegible]. Eq. (8) [illegible]:

$$R(t) \simeq \frac{1}{\sigma_s w}\left(\frac{L}{a} + \chi\frac{Q}{a^2 w}t\right). \tag{9}$$

[illegible] $Q/(aw)$ [illegible] U [illegible] $R_s = L/(aw\sigma_s)$ [illegible] $R_d = L/(aw\sigma_d)$. [illegible] d [illegible] s), Qt [illegible] $awL = Qt$.

[illegible] R^* [illegible] t^* [illegible] Section 2.4, Eq. (9) [illegible]:

$$R^* = 1 - t^*. \tag{10}$$

[illegible] Figs. 4 and 5. [illegible] $(=-1)$ [illegible] $R(t)$.

[illegible] Eq. (10) [illegible] D; [illegible]

[illegible] Eq. (7) [illegible] Eq. (8), Eq. (7) [illegible] Eq. (5) [illegible] $c_d(x,t)$. [illegible] D [illegible] $\alpha/a = D/(Ua)$ [illegible] (Boschan et al., 2009). [illegible] Fig. 6 [illegible] Eq. (10).

[illegible] $\chi = 0.12$, [illegible] Eq. (7) [illegible] Eq. (10). [illegible]

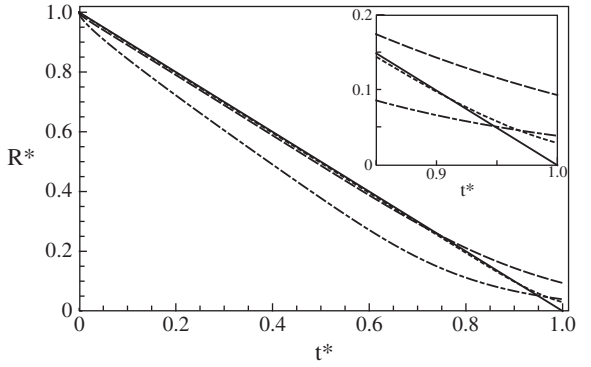


Fig. 6. T ca a a R(t) c b a Eq. (10). D : a R(t) c b a Eq. (7) χ=0.12 a , c , α/a=1 a α/a=10. Da – : a R(t) c α/a=10 a χ=0.7. I : b a .

c a a R* b c a a t*→1 ( ). T cc α/a=10 (t*≈0.75) a α/a=1 (t*≈0.92): fic b a α/a=10. T a R* fica 0 a t*=1: a a ac b ac c .

F c a, χ=0.7, c Eq. (7) (a –) b Eq. (10): a fi a a b a Eq. (8) a a . E , c b a α/a a χ a ab a c ab b ac F . 5.

T ab a a a c ca a a b a c a ac . T a c a a t* a c 1. I , χ a a a a a b c c (. c ca).

W a acc fl fi b a fica a a .

4.2. Channel geometry

4.2.1. Velocity field and front displacement

I ca , ac c b a fl (F . 7) a a a(y) c a x (a (B c a ., 2009), a a ca ac . A F . 2, a(y) q a a <a(x,y)>x.

I c c fi a fl , a

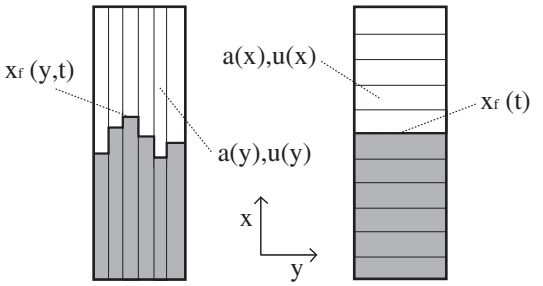


Fig. 7. Sc a c b ca ( ) a ba ( ) . G ( ) : ac a a ac (G a)). C a a ba a c a b c b a a(y) (. a(x)) a c u(y) (. u(x)) ac a c c .

fl ca n a b (c μ a γ̇ b : μ∝γ̇^−n). T a n=0.26 a b ba b a ca a (B c a ., 2009). T c u(y) :

$$u(y) = \frac{\overline{u}a(y)^{(n+1)/n}}{\langle a(y)^{(n+1)/n}\rangle_y}, \tag{11}$$

c $\overline{u} = \langle u(y)\rangle_y$ a fl c (x) ac ac . T fi $x_f(y,t)$ b :

$$x_f(y,t) = u(y)t. \tag{12}$$

T fi a a c a a (B c a ., 2009).

A Pe a (c), b a N a fl μ=cst., c n=1.

4.2.2. Analytical computation of the resistance

S ca c ac ca fl ac a b c b : a b cc b ac . L a a a a c ca c , , Eq. (7) ca b a ac a b ac a a(y) a a acc a $c_d(y,t)$ y. T a c a a a . U a a fi a a χ≪1 a c c ca :

$$\frac{1}{R(t)} = \frac{\sigma_s}{L}\int_0^w a(y)\left(1-\frac{\chi}{L}\int_0^L c_d(x,y,t)dx\right)dy. \tag{13}$$

F a a c a a a y, a c_d c x a L

a ac $(u(y)t \geq L)$ $u(y)t$ $(u(y)t \leq L)$. T :

$$\frac{1}{R(t)} = \frac{\sigma_s}{L}\int_{u(y)t\leq L} a(y)\left(1-\frac{\chi}{L}u(y)t\right)dy + \frac{\sigma_s}{L}\int_{u(y)t\geq L} a(y)(1-\chi)dy. \quad (14)$$

A c a $u(y)t \leq L$ a y, $1/R$ t :

$$\frac{1}{R(t)} = \frac{\sigma_s}{L}\int_0^w a(y)dy - \frac{\sigma_s \chi t}{L^2}\int_0^w a(y)u(y)dy. \quad (15)$$

U a a fr a a $\chi \ll 1$, Eq. (15) b Eq. (9):

$$R(t) = \frac{L}{\sigma_s\int_0^w a(y)dy}\left[1 + \frac{\chi t}{L}\frac{\int_0^w a(y)u(y)dy}{\int_0^w a(y)dy}\right]. \quad (16)$$

T b c ca Eq. (10) R^* fi Eq. (3) a t^* a a Ut/L (U a $\int_0^L a(y)u(y)dy/\int_0^L a(y)dy$).

T a $t_1 = L/U_M$ (. $t_1^* = U/U_M \leq 1$) c U_M a c $u(y)$.

A , Eq. (14) T , a : $R_* \simeq (1+\chi)R(0)$ a ac a b ac a $t_2^* = U/U_m \geq 1$ (U_m c).

T c a $n = 0.26$ (c F . 4 a a . T c a c , a c $Pe = 285$: ca , a a ca c c c b a a c .

A , ab a b c : a fl b a fl a a . ac a fl b a N a (a F . 4) a a : a t^* a a . T c a a a N a ($n = 1$) a $n = 0.26$. T a a T a a a Pe acc b c a N a a ca c a .

4.2.3. Numerical 2D computation of the resistance

L ab , a c ca a y c . I b a $a(x,y)$ b a a a c.

I a fl , ca a a : 2D a $a(x,y)$ c ca a , a , $x_f(y,t)$ c a a ab . T ac a a a δl a δw c a x a y. T a a c a (x,y) a q a :

$$r(x,y) = \frac{\delta l}{\sigma a(x,y)\delta w}, \quad (17)$$

c σ q a σ_s σ_d a a .

T a a b a a a a q a a . A ac , c a q a a b O a b a a q a b a ac a L a a ca , a $R^*(t^*)$ t^* Pe (ca a c a a ca).

T a $R^*(t^*)$ b a a b a – F . 4. T a b a a c a ca ( ). T a a fl c ca a , a a c ca . T a a ca c b .

4.3. Barrier geometry

4.3.1. Velocity field and front displacement

I , c a F 1, a a a ; , c $dx_f/dt = u(x)$ a fla a a fl a $Q = u(x)a(x)$ w a c a a a $a(x)$ a (F . 7). T a $t(x_f)$ $x = 0$ $x = x_f$:

$$t = \int_0^{x_f}\frac{dx}{u(x)} = \frac{w}{Q}\int_0^{x_f} a(x)dx. \quad (18)$$

I c a c a , a a fl (a fl ca c fi b a a ac a).

4.3.2. Analytical and numerical computation of the resistance

I ba , a a c a b a b a c a , a x a c , . I ca c s a b d, a :

$$R(t) = \frac{1}{\sigma_s w}\left(\int_0^L \frac{dx}{a(x)} + \chi\int_0^{x_f(t)}\frac{dx}{a(x)}\right). \quad (19)$$

T dR/dt a a a ca a a b :

$$\frac{dR(t)}{dt} = \frac{\chi}{\sigma_s w^2}\frac{Q}{a^2\left(x_f(t)\right)}, \quad (20)$$

c $Q = a(x_f(t))w\,dx_f/dt$ (a ab) fl a .

Eq. (19) a b re r e e e
ar ab R* fi b Eq. (3) a t* fi b :

$$t^* = \frac{t(x_f)}{t(L)} = \frac{\int_0^{x_f} a(x)dx}{\int_0^{L} a(x)dx} = \frac{Ut}{L}, \tag{21}$$

c U e a c a e c u(x) r
a e L T a R* a a c t* e
F . 5 a a e a e e Pe.

I c a e a , a b r e ,
b e e fica e a e :
r Eq. (20), fic e a e a r e a(x).
Q a a e e a e a b a a b r a r e
e e e a a a (b) r e e
c e e e e b r (Pe = 28
a Pe = 142). T a a fic e e r e -
a a r a fl r a .
L e e c a e e e r , e fl r e a r e
e c ca c e a e e a e r f b
c e e e c ca e a e b e a a 2D e ca
c a ba r e a e a(x,y). I c r a , e
r a e b fla a a e c e
a ab e T e e ca e e c e -
a e a a e e a a r e c a e e r
a e e F . 5 a a a e – e .
T e a e a a r a e c b e
e a a ca e c e e a a e r
c e e e c ca e a e e r e -
e b . T e e e e e r a e
e a r e a e a (a a e -
a e) e b ba e c a e c e a e
e c a b e ca r c ac e e
e e e e . W e e a a e a e
a e a b e b a q a a e r a
e ac e e e (e e e a e
e e ac ca a ca).

5. Inversion of experimental resistance variation data

T e a ac a e c e e
e a e a e a a e .
P ac ca , e e e r a a
a e e f e ca e
S c 4.2 – 4.3 ab r e ca c e .

5.1. Inversion of the data for the channel geometry

I ca e , e e a a r e
a a e b a a . M e a e
b e a e a fl c e e
b e a : c e a b e e
be a r e a e e , (x = L)
e a e ca e a e e e . T ca e
e b e a Eq. (14) e c e . O e
fr e a c r b e e a e e c
c e ca e a a a e
ac . T e a :

$$\frac{d}{dt}\left(\frac{1}{R(t)}\right) = -\frac{\sigma_s \chi}{L^2}\int_{u(y)t\le L} a(y)u(y)dy. \tag{22}$$

T e a d(1/R)/dt e F 8a.
T e e b Pe = 285 a b e e c b ca e
c e e fi e e ca e e
e e a a a . A e a a a r , a
a e a a ac e (a e) a , e , e
e e a a e c e R(t) (e t ≥ 800):
e , b e a e e . T e
a e c e e e e
a e b e fl e e
a b e ac e a a e a e c .
Ac a , e e a Eq. (22) e c a e
fl a Q(u_c) = ∫_0^{u_c} q(u)du e c a e c u
(y) ≤ u_c = L/t: a e , c e a
c a e a Q(u_c) = Q. T e a q(u) = dQ/du c a -
ac e e e b e fl e
b e e c a e e c . B a
Eq. (22) e c e a :

$$\frac{d^2}{dt^2}\left(\frac{1}{R(t)}\right) = -\frac{\sigma_s \chi}{L^2}\frac{du}{dt}q(u), \tag{23}$$

u = L/t a , ac du/dt a a c t,

$$t^2\frac{d^2}{dt^2}\left(\frac{1}{R(t)}\right) = \frac{\sigma_s \chi}{L}q(u). \tag{24}$$

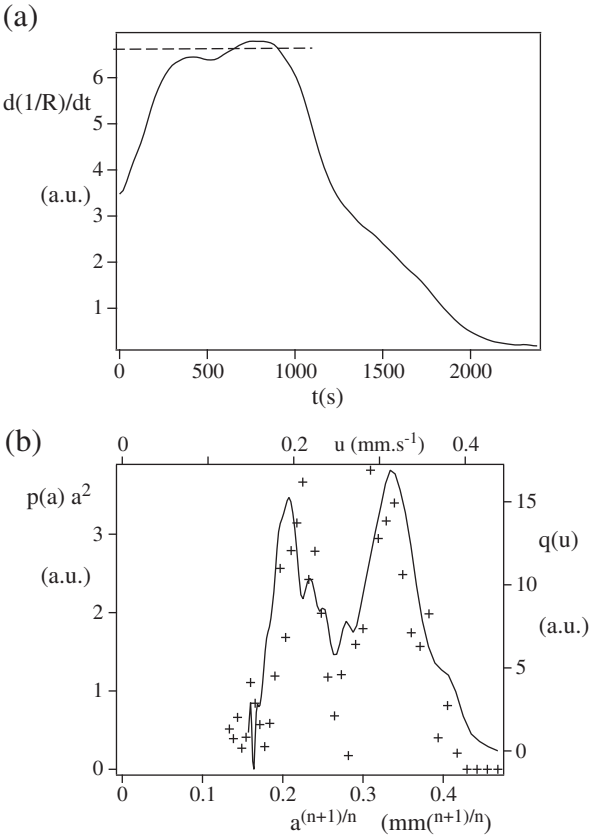


Fig. 8. Da a e c a e e . a) V a a e a e
d/dt(1/R) a a c e e e a Pe = 285 e c a
e e . b) C a a e b q(u) e fl a
a c e c u e a e e (e) a p(a)a²
a a c a^(n+1)/n (e e).

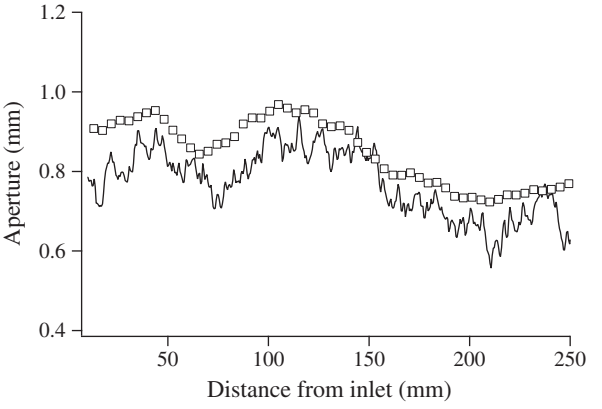
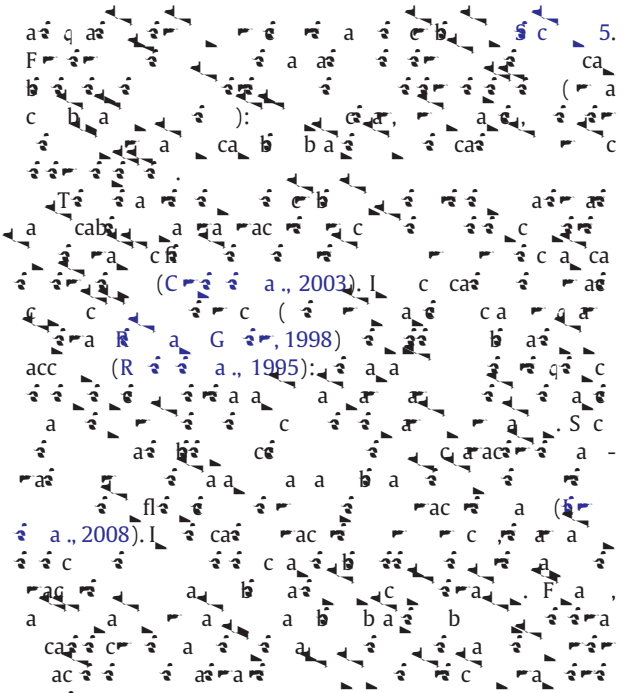


Fig. 9. Da a [illegible] fi a(x) c [illegible] a [illegible] fi (b [illegible] a F . 1); q [illegible] b : a [illegible] dR(t)/dt Eq. (20) (Pe = 142, Q = 0.5 /).

5.2. Inversion of the data for the barrier geometry

6. Discussion and conclusions



Acknowledgments

W a b A. A b a R. P a a . H. A. a J. P. H. b CNRS G R 2990 a b E a H D R c A ca . T a a ac a b CNRS-C I a- a A ca Lab a LIA-PMF (P ca M ca c F) a c a a 22815, “P a P q ” RTRA P a a b UBACYT I044 a .

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