- Techniques de mesure
  (taux de vide)

- Modèles de taux de vide.
  Calcul pratique.

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RAPPELS des OPERATEURS de MOYENNE.

- Fonction indicatrice de phase

$$X_k(r,t) = 1 \text{ si } M(r) \in \text{phase } k$$

- Moyennes spatiales

phasique : $\langle f \rangle_n = \dfrac{1}{\mathcal{D}_{kn}} \displaystyle\int_{\mathcal{D}_{kn}} f \, d\mathcal{D}_{kn}$

globale : $\langle\!\langle f \rangle\!\rangle_n = \dfrac{1}{\mathcal{D}} \displaystyle\int_{\mathcal{D}} f \, d\mathcal{D} \quad \left(\mathcal{D} = \bigcup_k \mathcal{D}_k\right)$

- Moyennes temporelles

conditionnelle : $\overline{f}^{X} = \dfrac{1}{T_k} \displaystyle\int_{[T_k]} f \, dt$

globale : $\overline{f} = \dfrac{1}{T} \displaystyle\int_{[T]} f \, dt$

$[T]_k$ ensemble des instants où $X_k = 1 \; \cap [T]$

$[T]$ intervalle d'intégration $\left[t - \frac{T}{2}, t + \frac{T}{2}\right]$

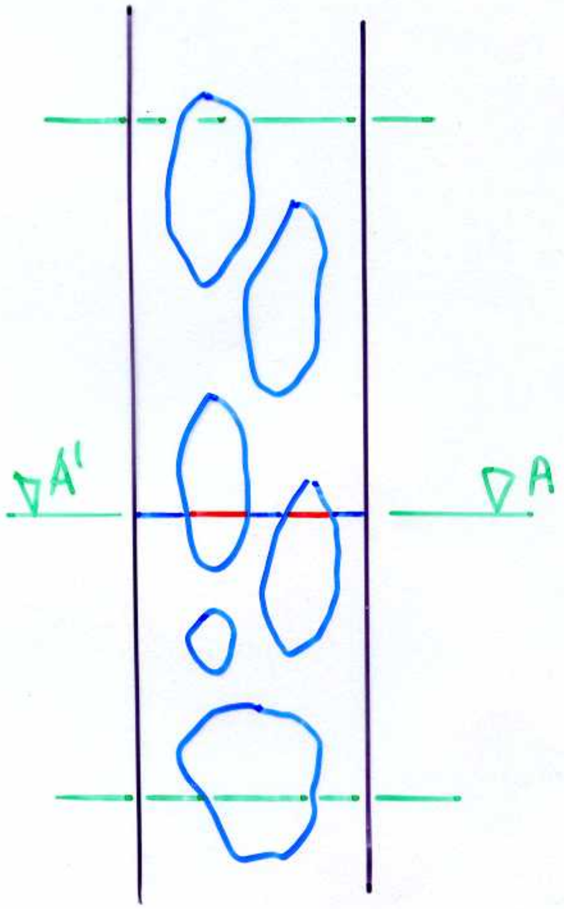
IDENTITÉ : $\overline{R_{kn} \langle f \rangle_n} = \langle\!\langle \alpha_k \overline{f}^{X} \rangle\!\rangle_n$

LES DEFINITIONS du TAUX de VIDE (α)

- Taux de vide local α_G

temps de présence moyen : $\alpha_G \triangleq \dfrac{T_G}{T_G+T_L} = \dfrac{T_G}{T}$

- Fractions spatiales de gaz/vapeur/vide instantanées



- fraction linéique instantanée

$$R_{G1} \triangleq \frac{L_G}{L_G+L_L} = \frac{L_G}{L}$$

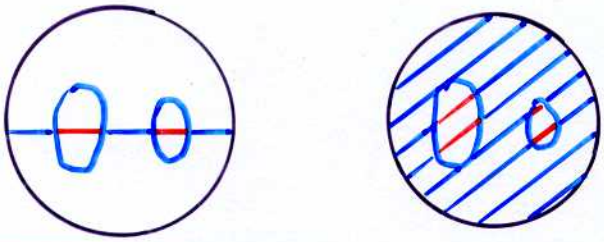
- fraction surfacique instant.

$$R_{G2} \triangleq \frac{A_G}{A_G+A_L} = \frac{A_G}{A}$$

- fraction volumique instant.

$$R_{G3} \triangleq \frac{V_G}{V_G+V_L} = \frac{V_G}{V}$$

Coupes A-A'



RELATIONS FONDAMENTALES
IDENTITÉS

- Rappel Commutativité des opérateurs

$$\overline{R_{kn}\langle f\rangle_n} = \langle\!\langle \alpha_k \overline{f}^x \rangle\!\rangle_n \quad (\text{avec } f \equiv 1)$$

- Taux de présence (vide) moyen

+ sur une ligne

$$\overline{R_{G1}} \triangleq \frac{1}{T}\int_{[T]} R_{G1}\,dt \equiv \frac{1}{L}\int_L \alpha_G\,dL$$

+ sur une surface

$$\overline{R_{G2}} \triangleq \frac{1}{T}\int_{[T]} R_{G2}\,dt \equiv \frac{1}{A}\int_A \alpha_G\,dA$$

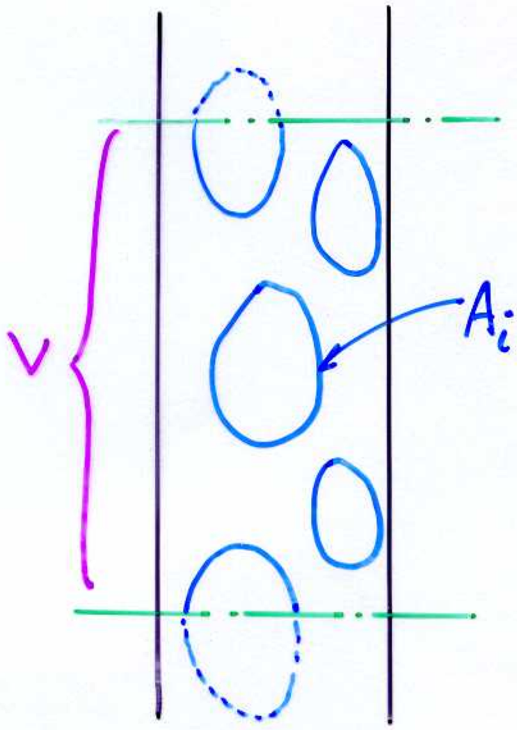
+ dans un volume

$$\overline{R_{G3}} \triangleq \frac{1}{T}\int_{[T]} R_{G3}\,dt \equiv \frac{1}{V}\int_V \alpha_G\,dA$$

- Les définitions sont précises.

AUTRES DEFINITIONS

- Aire interfaciale volumique (instantanée)



$$\Gamma_3 \triangleq \frac{A_i}{V}$$

- Aire interfaciale locale

$$\gamma = \sum_{\substack{\text{discont.} \\ \in [T]}} \frac{1}{|v_i \cdot n_k|}$$

- Identité :

$$\overline{\Gamma_3} \equiv \langle \gamma \rangle_3$$

TECHNIQUES de MESURE du TAUX de VIDE.

- Taux de vide local

  Sondes électriques
  Sondes optiques } α et γ

- Taux de présence sur une ligne

  Atténuation des Rayons X ou γ.

- Taux de présence surfacique

  Rayons X ou γ : one-shot technique
  Densitomètre multi faisceaux
  Diffusion de neutrons
  Densitomètre à impédance (ép. de film)

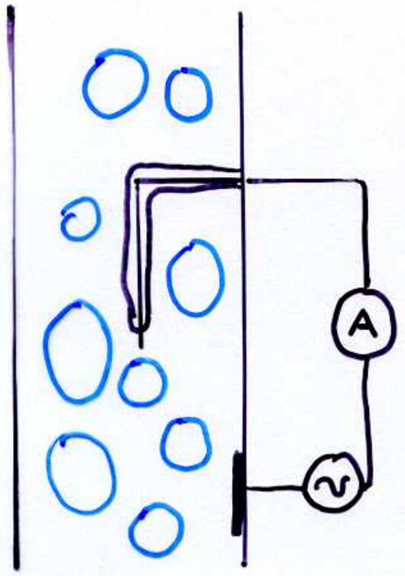
- Taux de vide moyen (volumique)

  Vannes à fermeture rapide
  Méthodes ultrasonores (α, a_i, d_{sm})

TAUX de VIDE LOCAL

Mesure de la FIP ($X_k(r,t)$)

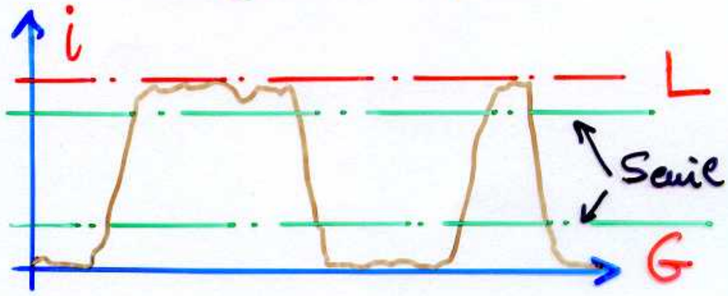
- Sondes résistives (resistivité)



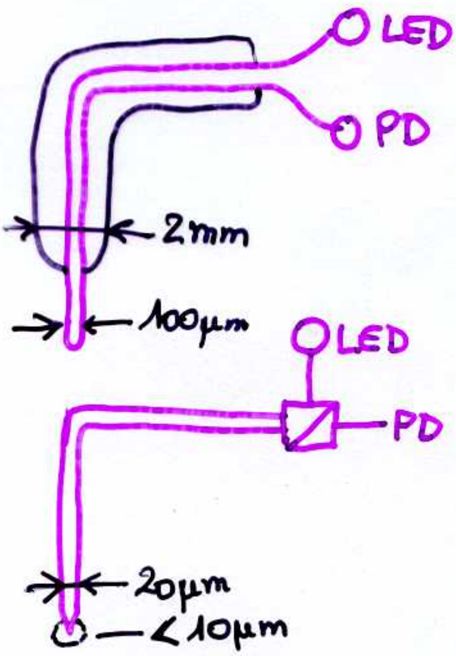
Milieu continu conducteur

Phase dispersée isolante

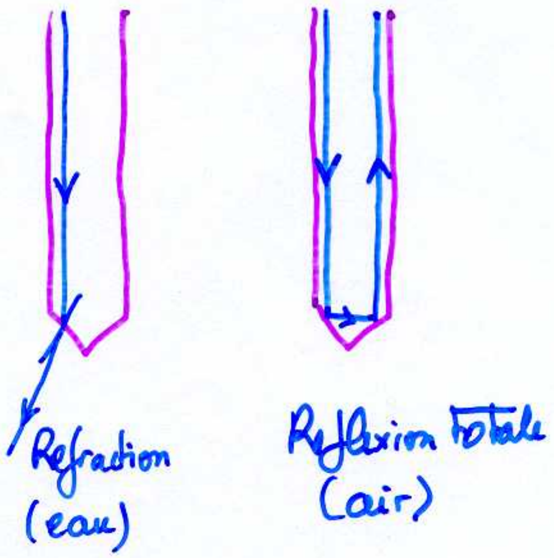
Seuillage : α (seuil)



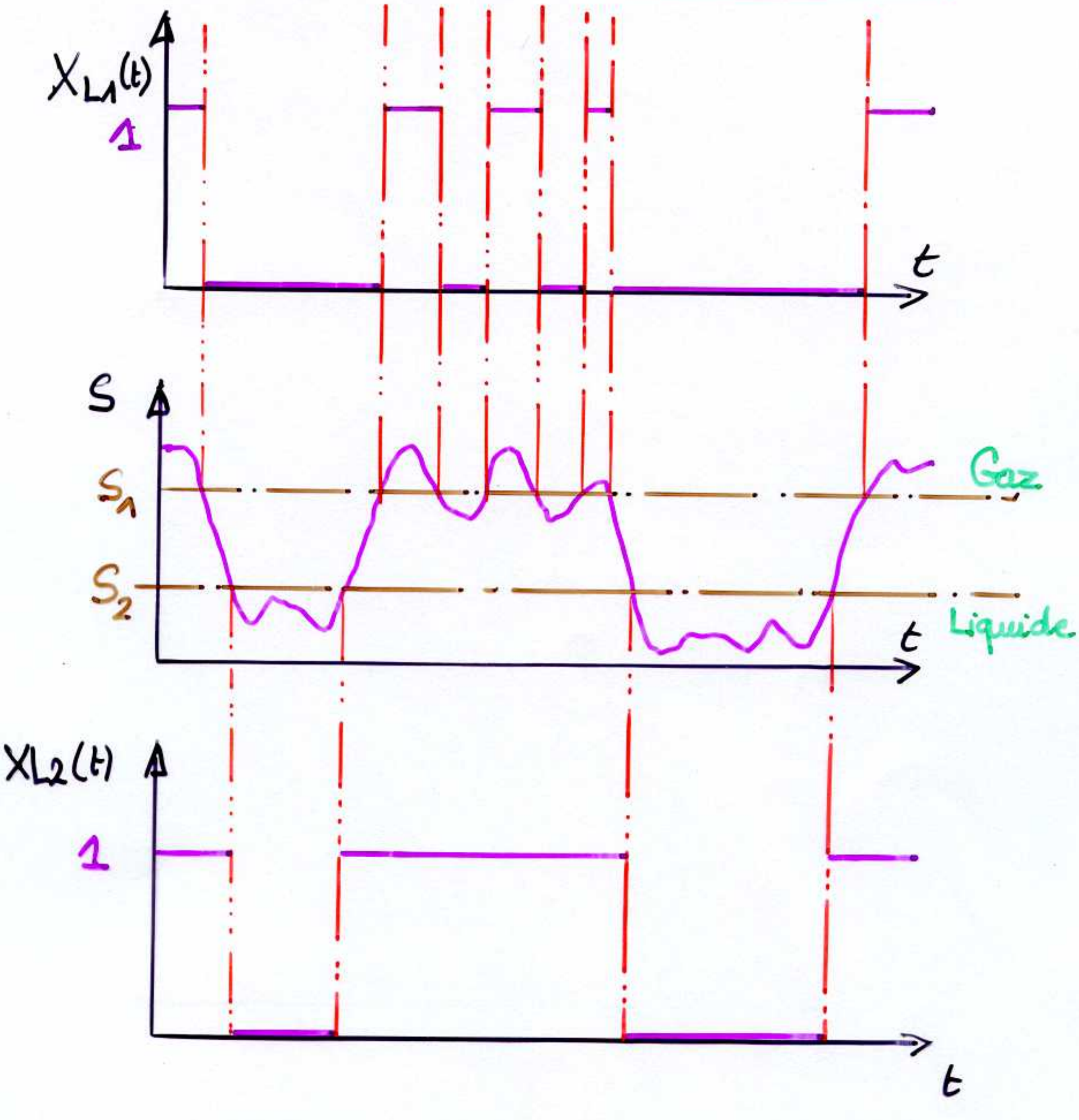
- Sondes optiques (indice optique) { eau, freon, T<110°C



Pointe de la fibre



DETERMINATION des SEUILS



- Détermination du seuil s. $\alpha_1 < \alpha_2$!

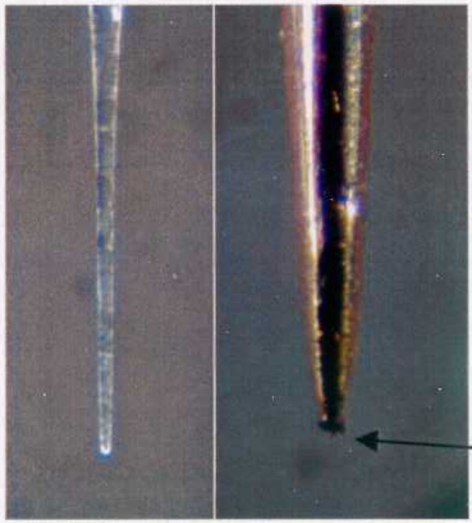
Méthode de référence ex $\Delta P \Rightarrow \overline{R_G}$

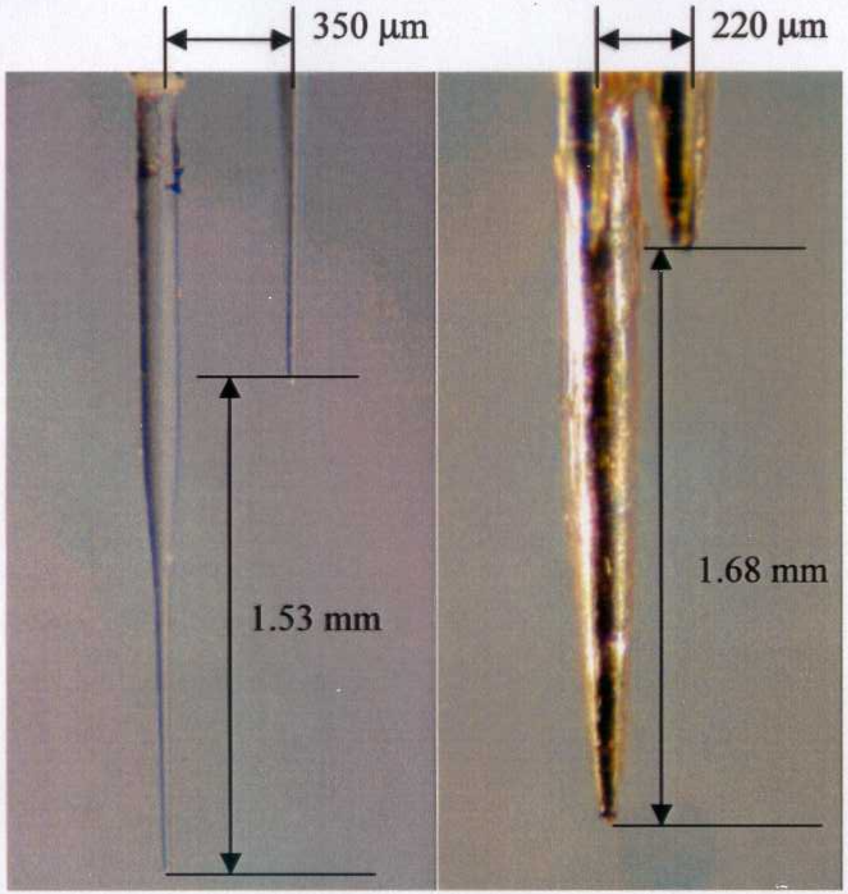
$\alpha_G(s) = \dfrac{T_G(s)}{T}$; profil ds une conduite

Ajustement s / $\langle \alpha_G(s) \rangle = \overline{R_G}$

Optical vs Electrical four-sensor probe

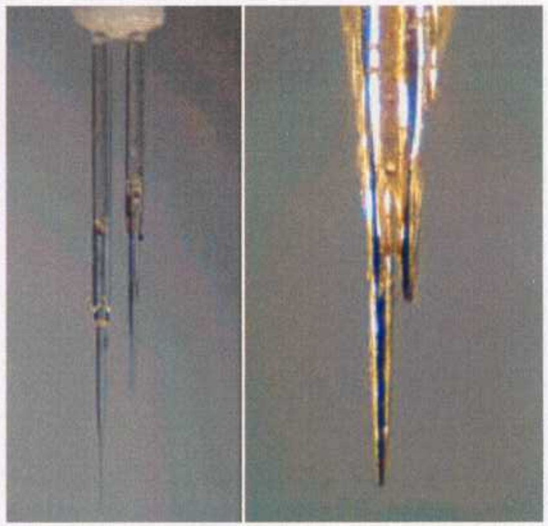
$\phi_{cond} \approx$ **200 μm**
$\phi_{opt} \approx$ **50 μm**

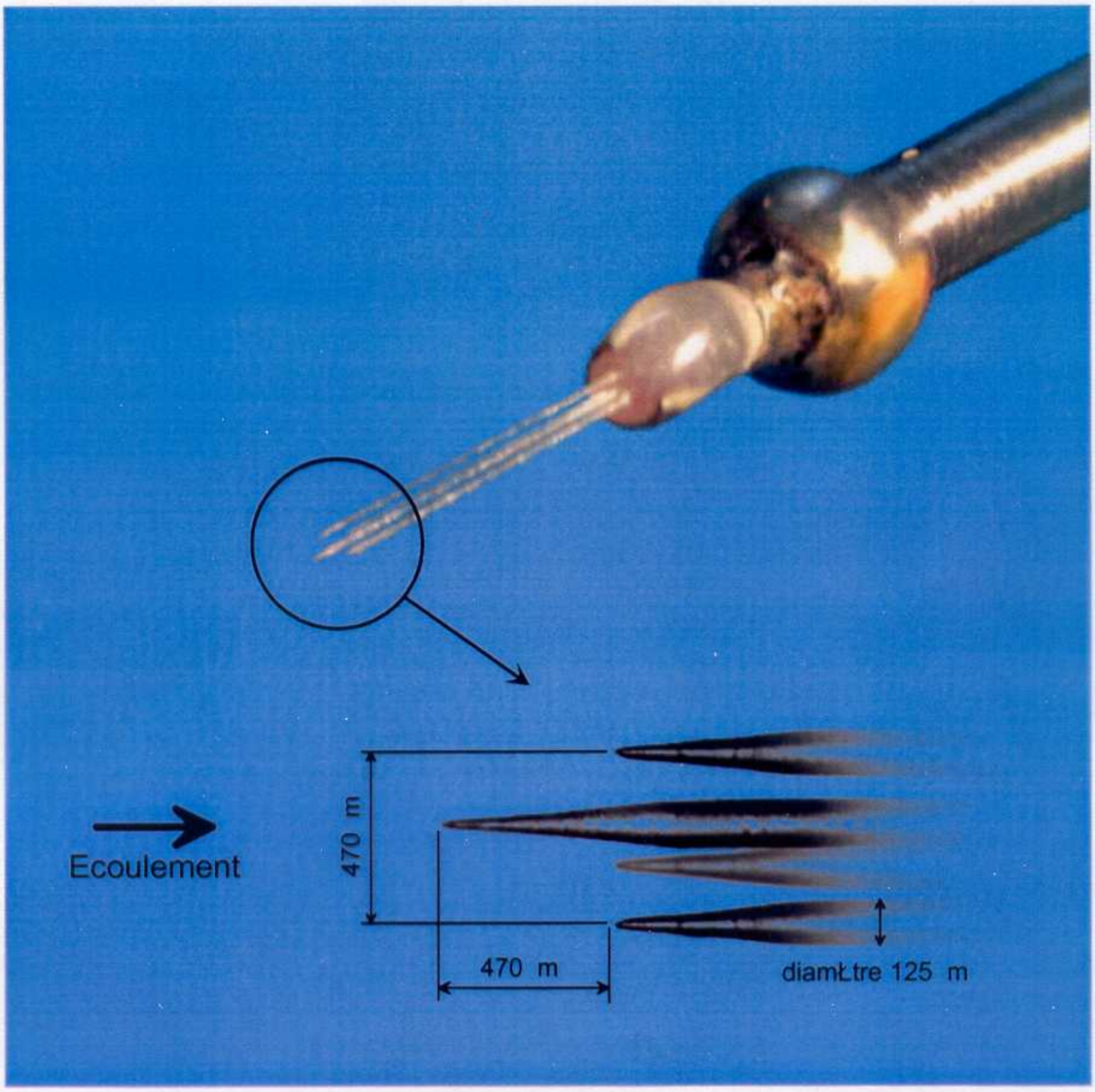




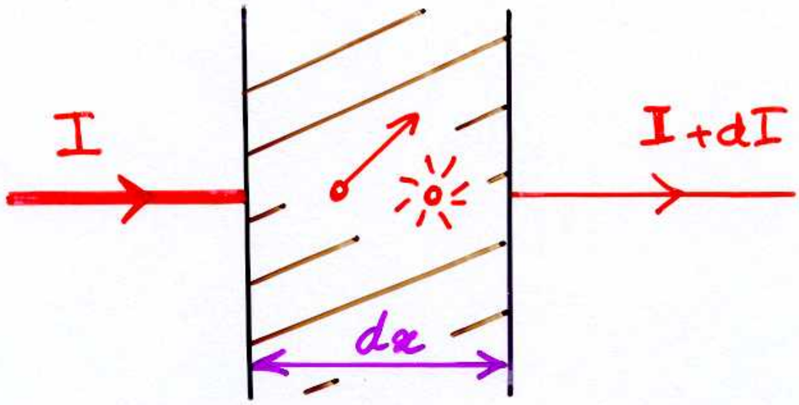
Sensitivity tip ≈ 10 μm

Overall view




Ecoulement
470 m
470 m
diamŁtre 125 m

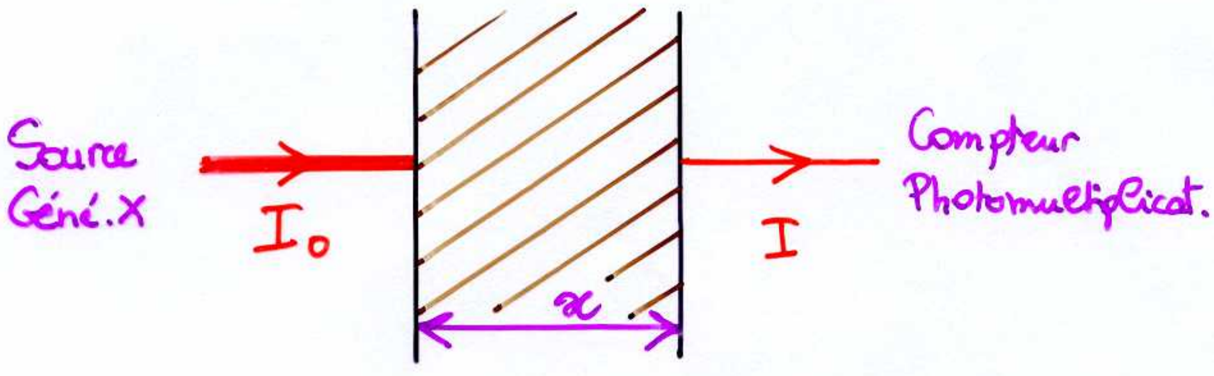
ATTENUATION RX ou γ
Méthodes Photoniques



Loi de Beer-Lambert :

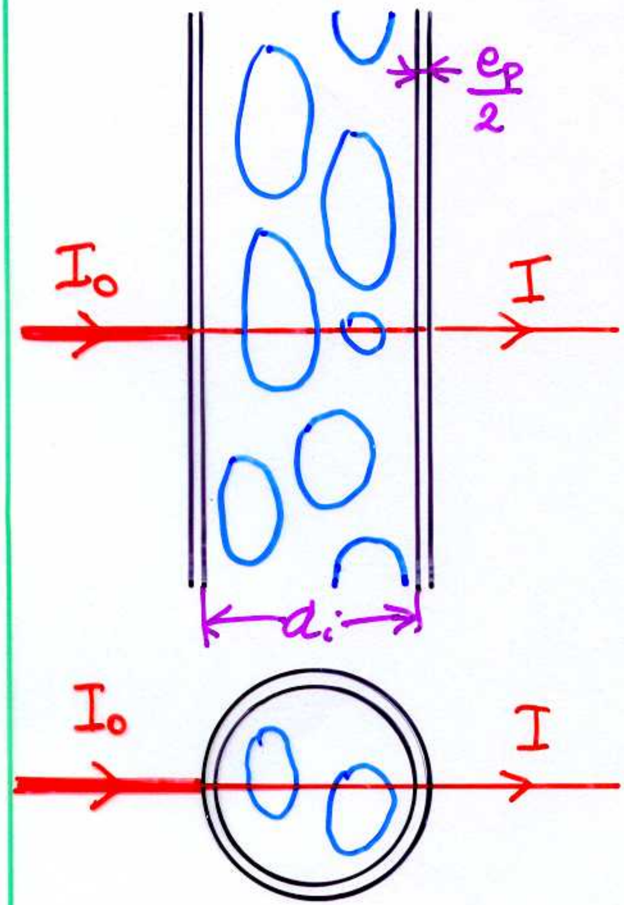
faisceau collimaté, monoenergie (raie)

$$dI = -\mu I dx \qquad [\mu] = L^{-1}$$



$$I = I_0 \exp(-\mu x) = I_0 \exp\left(-\left(\frac{\mu}{\rho}\right)\rho x\right)$$

FRACTION LINÉIQUE de Phase



- Loi de Beer Lambert

$$I = I_0 \exp(-\mu_p e_p) \cdot \exp(-\mu_L (1-R_{G1}) d_i) \cdot \exp(-\mu_G R_{G1} d_i)$$

$$R_{G1}(z,t) \triangleq \frac{L_G}{L_G + L_L} = \frac{L_G}{d_i}$$

- Approximation Basse Pression

Monophasique Gaz : $I_G = I_0 \exp(-\mu_p e_p)$

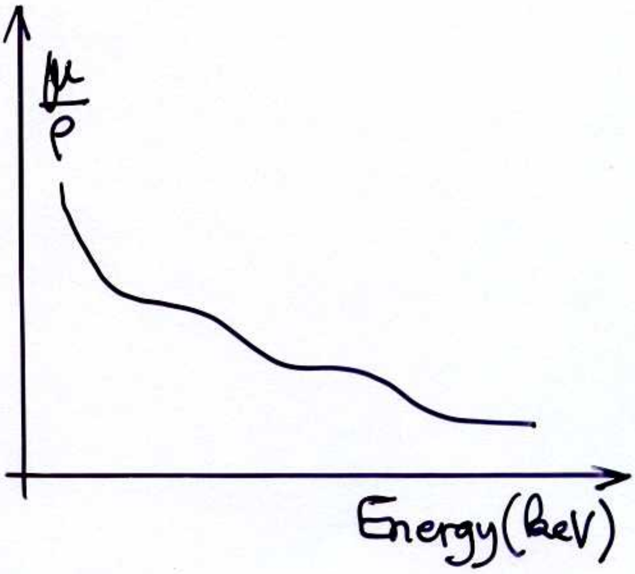
Monophasique Liquide : $I_L = I_0 \exp(-\mu_p e_p) \exp(-\mu_L d_i)$

Ecoulement diphasique : $I = I_0 \exp(-\mu_p e_p) \exp(-\mu_L (1-R_{G1}) d_i)$

Elimination $I_0, \mu_p e_p \Rightarrow$ $R_{G1} = \dfrac{\operatorname{Log} I/I_L}{\operatorname{Log} I_G/I_L}$

SOURCES D'ERREURS

- Contraste



$$\frac{I_G}{I_L} = \exp\left(\frac{\mu_L}{\rho_L}\right)\rho_L d_i$$

→ travailler à Basse En.

- Erreurs statistiques

$I \propto N$; $\frac{\Delta N}{N} = \sqrt{\frac{1}{N}}$ → travailler à haute Energie

- Fluctuations du taux de vide

Mesure de $[I] = \int_0^\tau I\,dt$ et $I(t) \propto \exp R_G(t)$

$\overline{\exp f} \neq \exp \overline{f}$ (non linéarités!)

ex: écoulement à poches $\Delta R_G \sim 0{,}20$, agité $\Delta R_G \sim 0{,}05$

- Stabilité de la source

$I_0(t)$ → méthode a faisceau de ref. $I \to \frac{I}{I_0}$

- Durcissement du spectre (f. multienergie)

filtres, spectrométrie, etalonnage direct

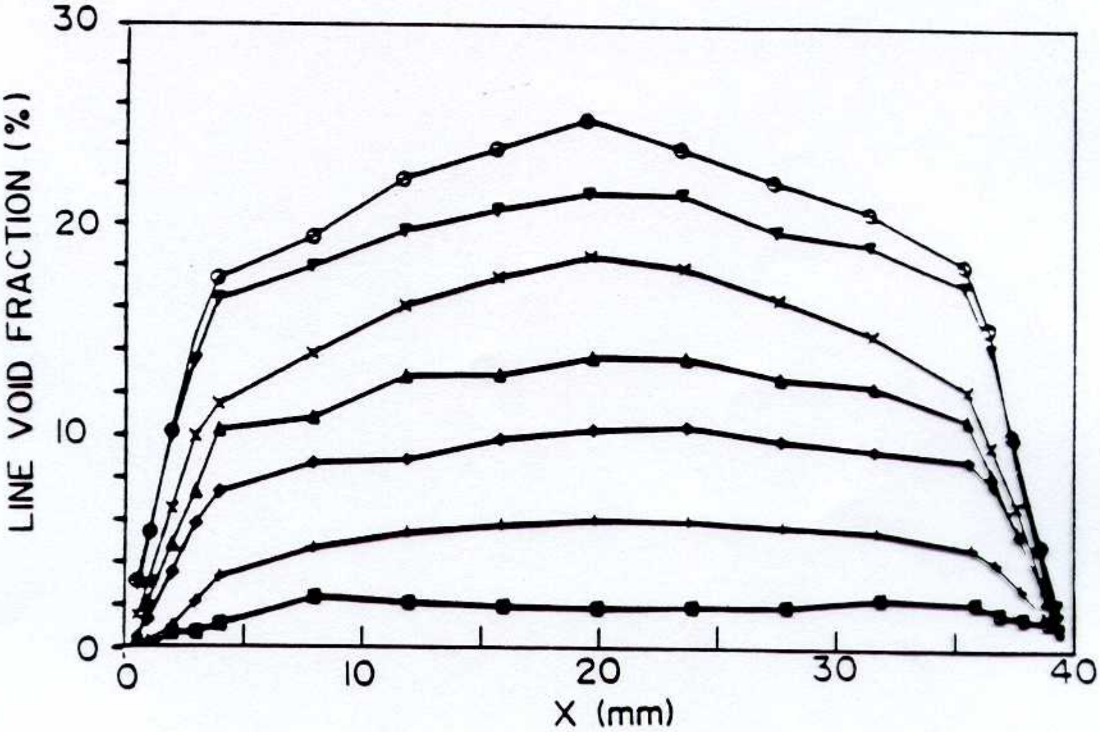


Figure 11 : Void fraction profiles for stagnant flow (v_l = 0, L = 40 mm). (□ ε = 0.01 ; + ε = 0.04 ; ◇ ε = 0.07 ; △ ε = 0.10 ; × ε = 0.13 ; ▽ ε = 0.16 ; ○ ε = 0.19).

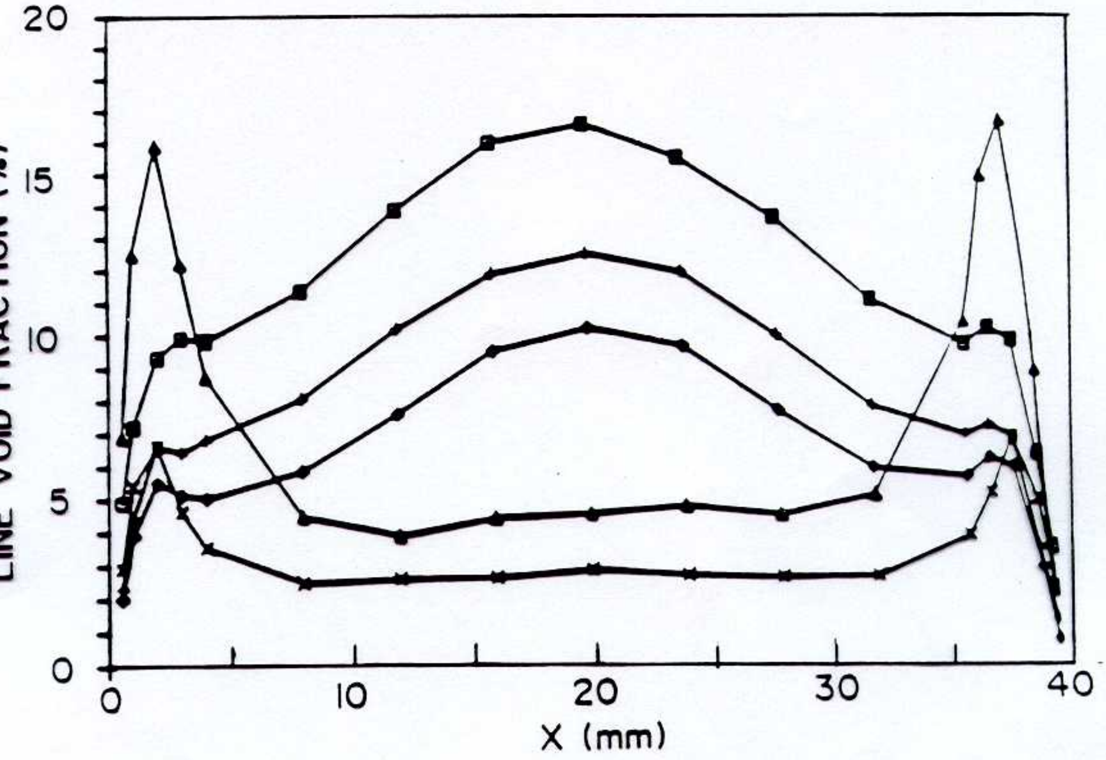
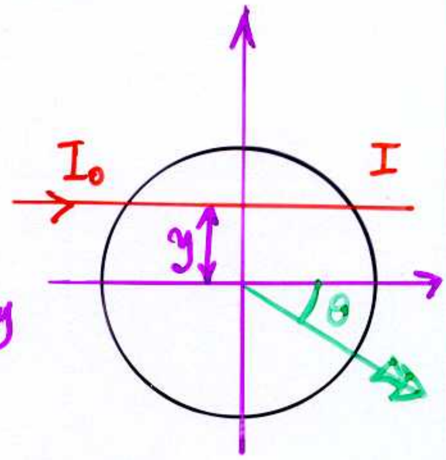


Figure 12 : Void fraction profiles for forced-circulation flow (v_l = 2.0 m/s, L = 40 mm), (× m_g = 0.1 g/s, ε = 0.030 ; △ m_g = 0.3 g/s, ε = 0.061 ; ◇ m_g = 0.4 g/s, ε = 0.069 ; + m_g = 0.5 g/s, ε = 0.089 ; □ m_g = 0.7 g/s, ε = 0.123).

TAUX de VIDE SURFACIQUE.

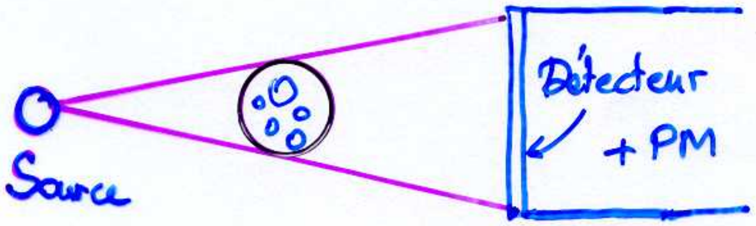
- Atténuation des Rayons X



  - Moyenne spatiale $\overline{R_{G2}}$

$$\overline{R_{G2}} = \frac{1}{\pi R^2} \int_{-R}^{R} 2 R_{G1}(y) \sqrt{R^2 - y^2}\, dy$$

  - Valeur Instantannée R_{G2}

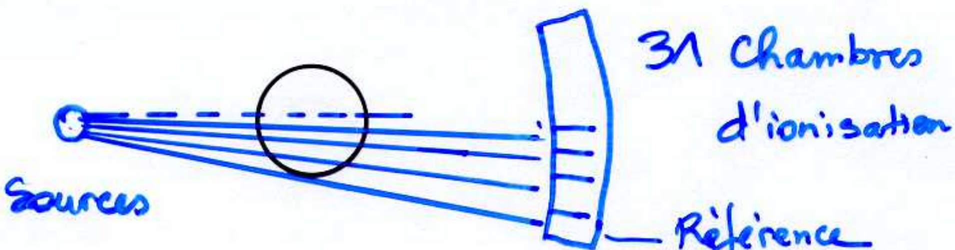


Limitations

$\Delta R_{G2} \leq \pm 0{,}05$

$0 < R_{G2} < 0{,}8$

  - Densitomètre multifaisceaux (31)



- Tomographie à Rayons X

  On mesure $\overline{R_{G1}}(y, \theta) \xrightarrow{\text{Inversion}} \alpha_G(r, \theta)$

- Diffusion de neutrons
  - traverse l'acier, diffusés + par l'eau.

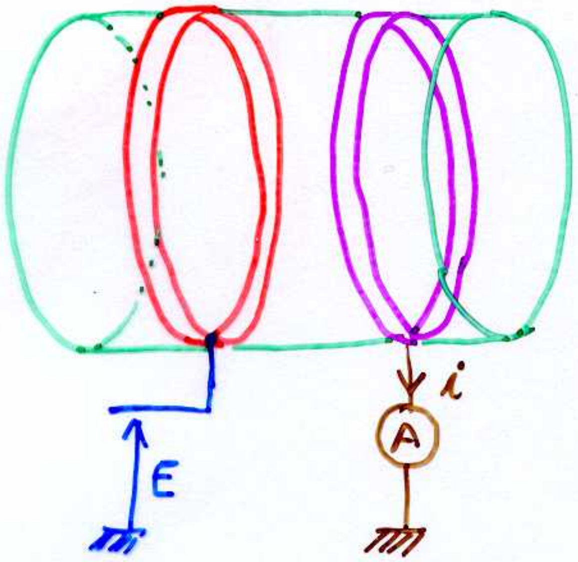
DENSITOMETRES à IMPEDANCE

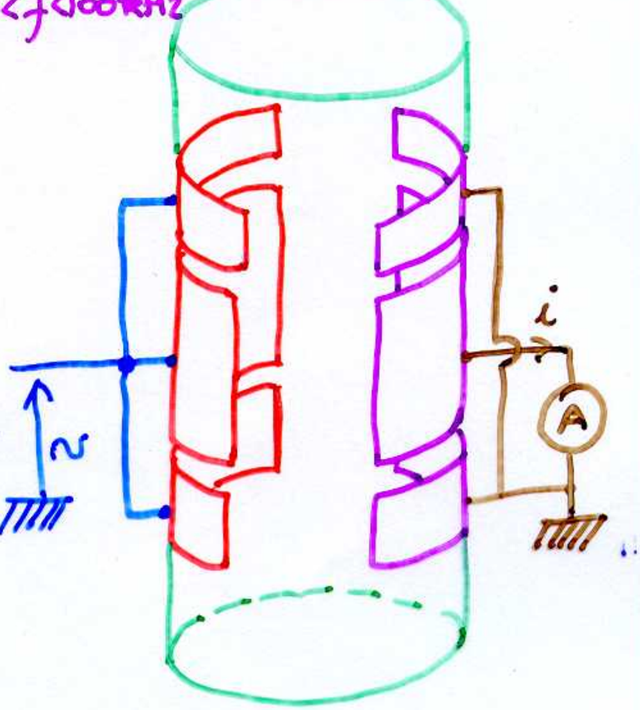
- Détermination impédance électrique 2ϕ

  — resisitif : $\sigma_{2\phi}$

  — Capacitif : $\varepsilon_{2\phi}$

$10 < f < 100\,kHz$





- Excitation $E\sim$ signal i

$$I = D\,E\,\sigma_c(T, c_1, c_2 \ldots)\, f(R_{G3}, \ldots)$$

- $R_{G3} \sim R_{G2}$ évolution lente ; $R_{G2}(t)$
- Méthode de référence $I_0 = E\,\sigma_c(T, c_1, c_2)\, f_0$
- Etalonnage / Modèle mél. $f(R_{G2}, \ldots)$
- Optimisation géométrique $f(R_{G2}, X)$

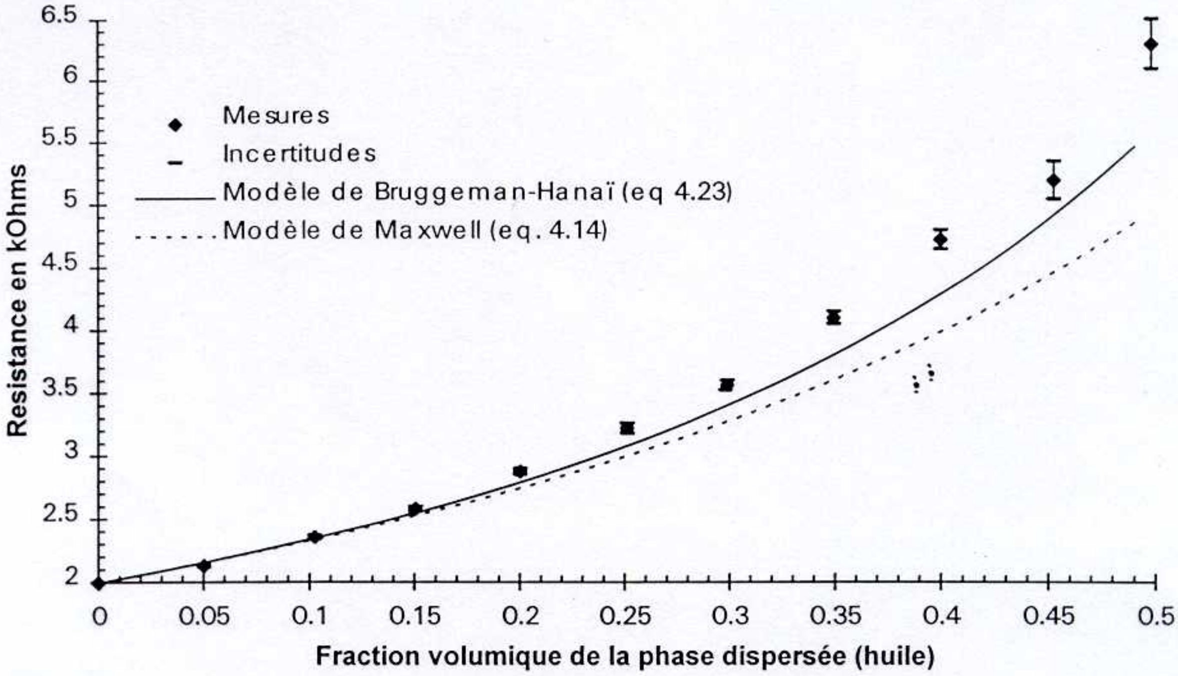


Figure 4.9 : Tracé de la résistance mesurée et calculée pour un écoulement eau-huile, lorsque la vitesse moyenne de l'écoulement est 56,6 cm/s et la température 18 °C ± 0,3.

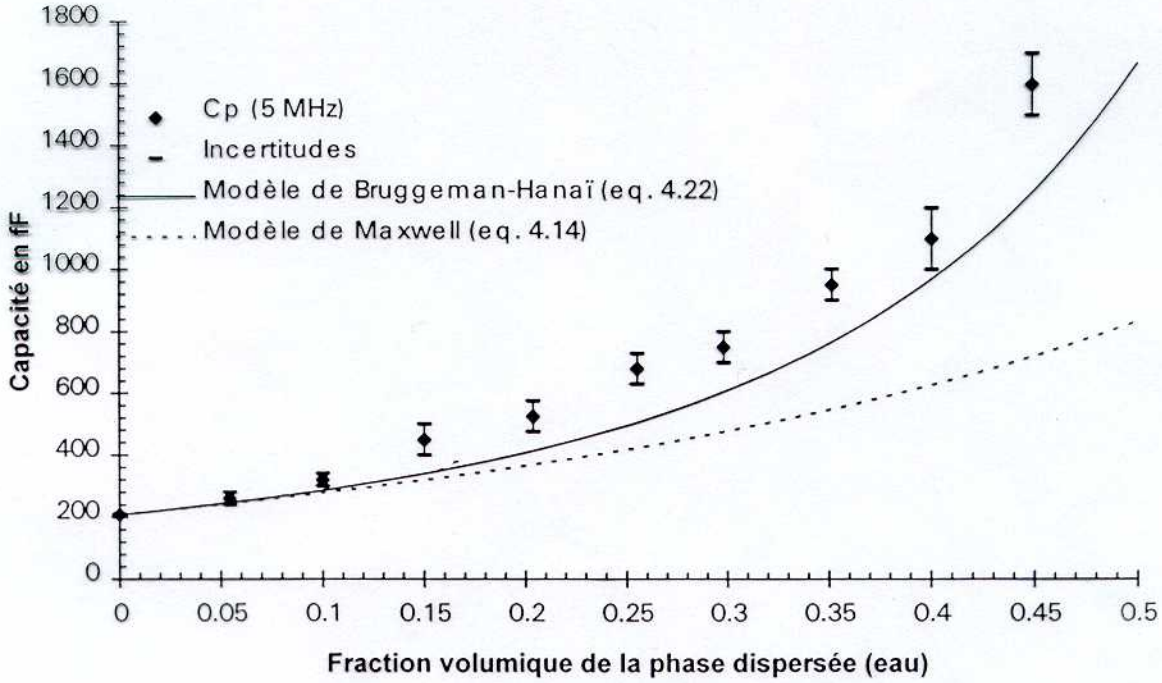
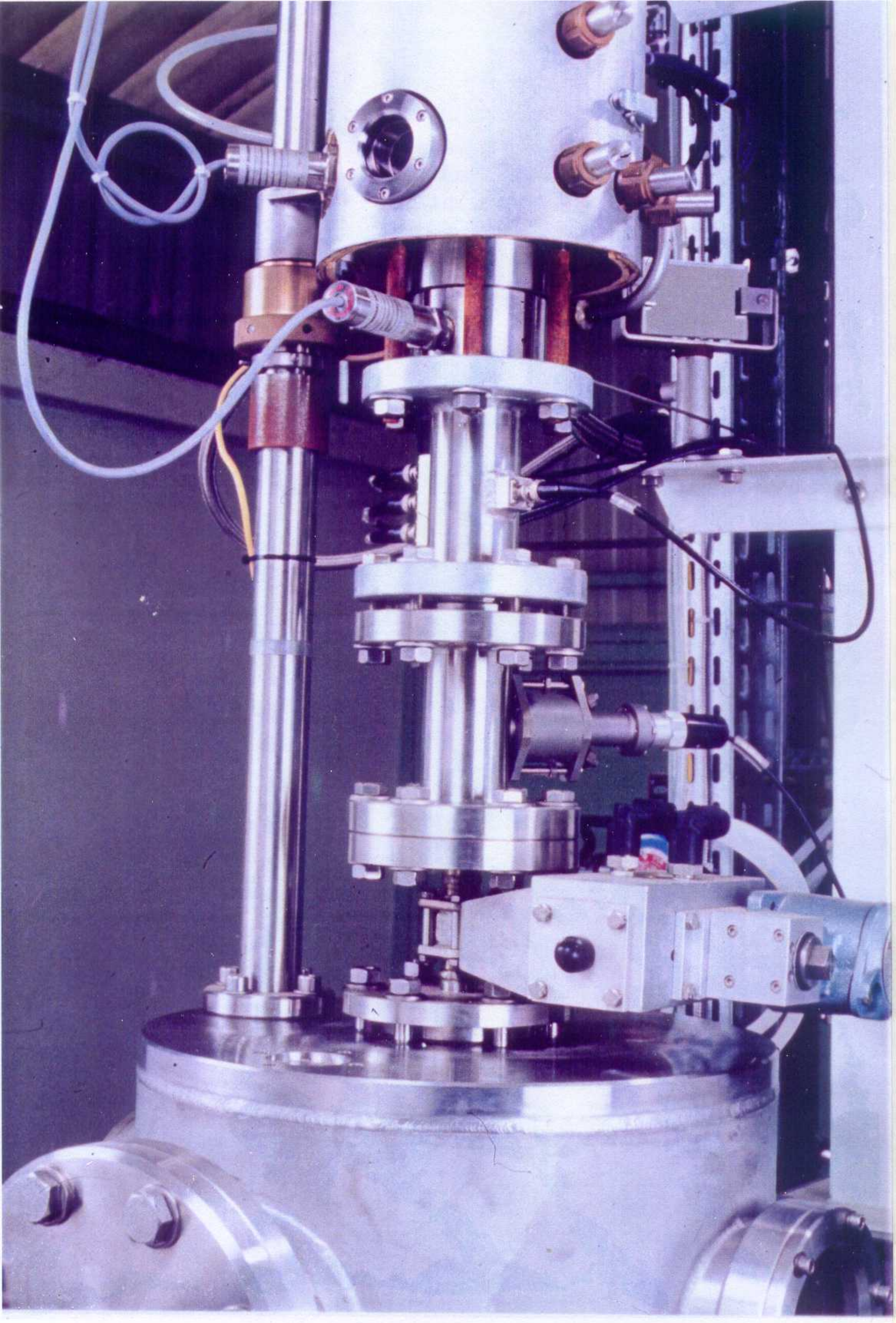
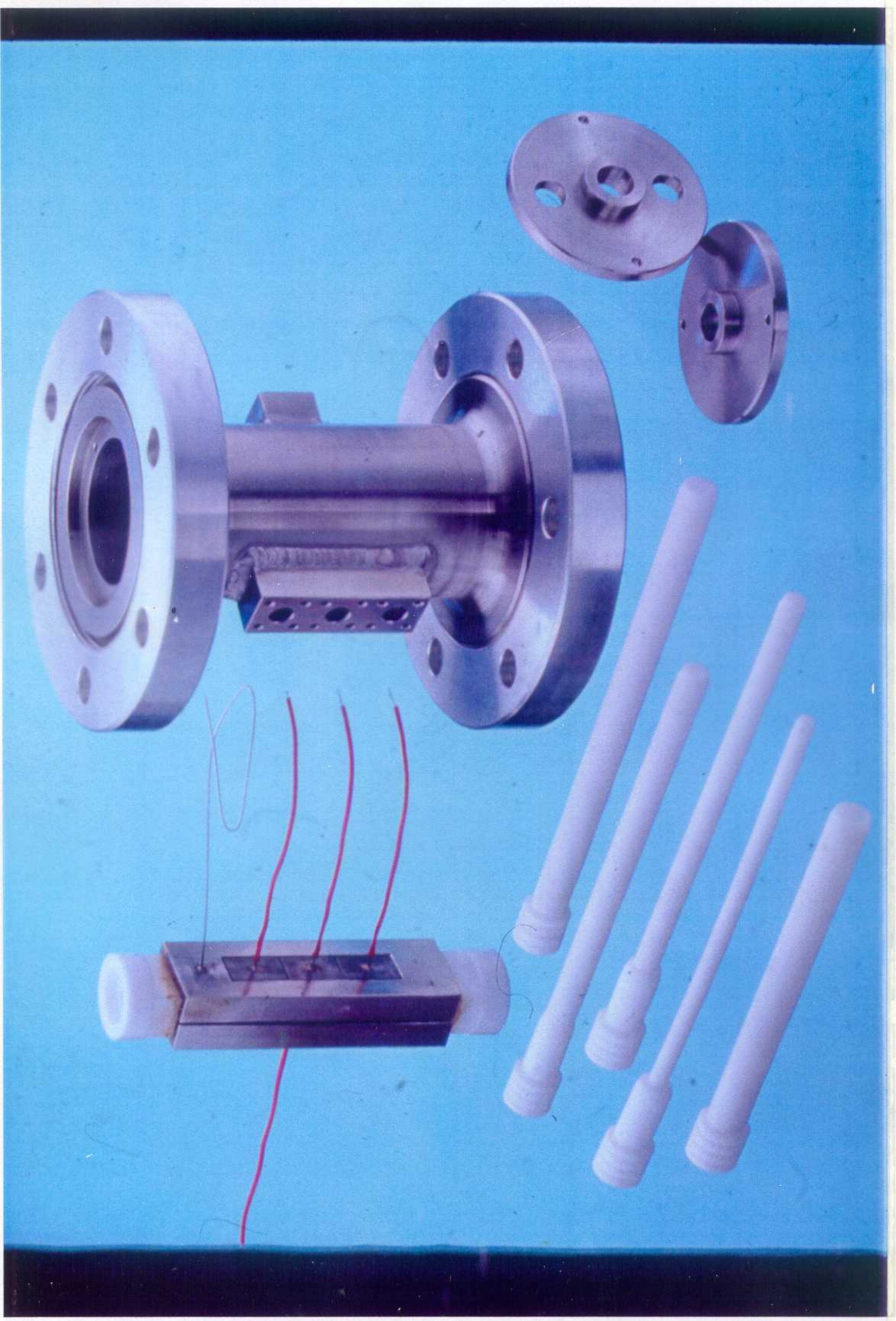
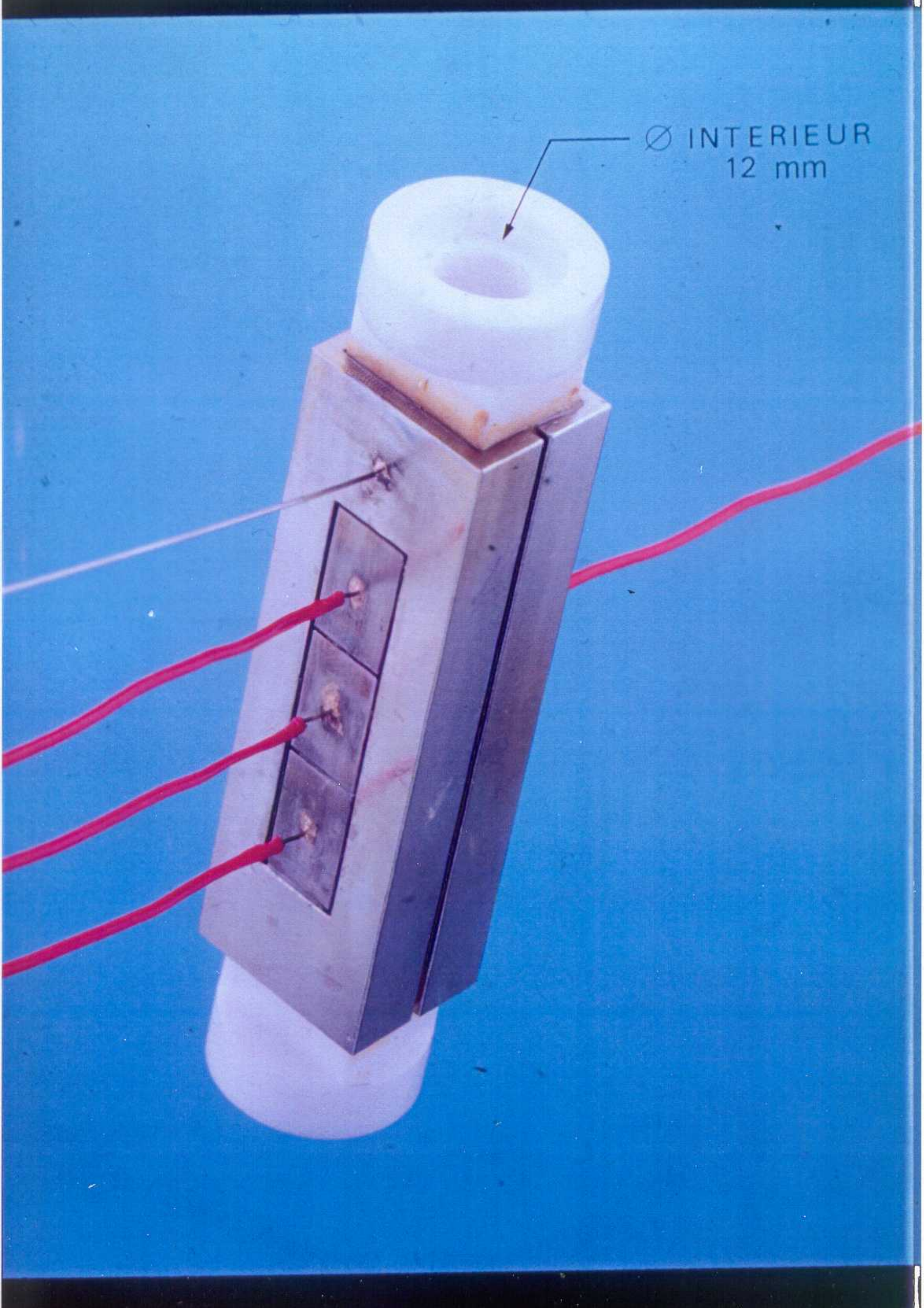


Figure 4.10 : Tracé de la capacité mesurée et calculée en écoulement huile-eau, lorsque la vitesse moyenne est de 56,6 cm/s et la température de 19,5 °C ± 0,1.

d'après Boyer, C. (1996)

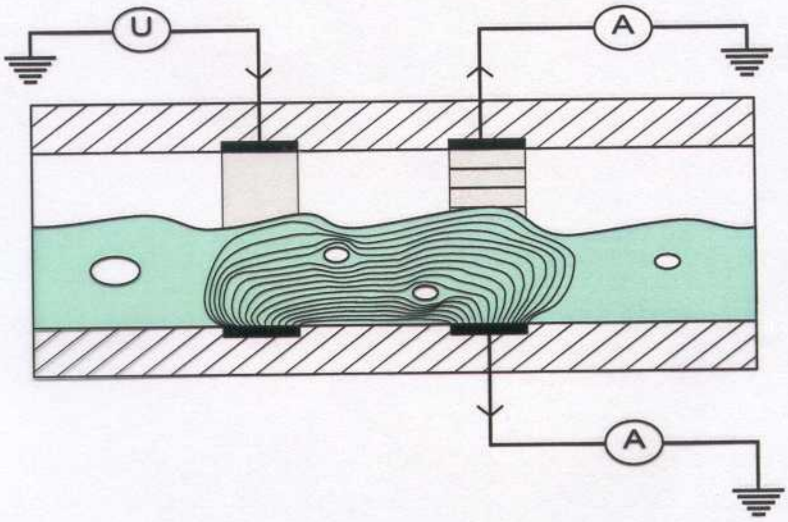




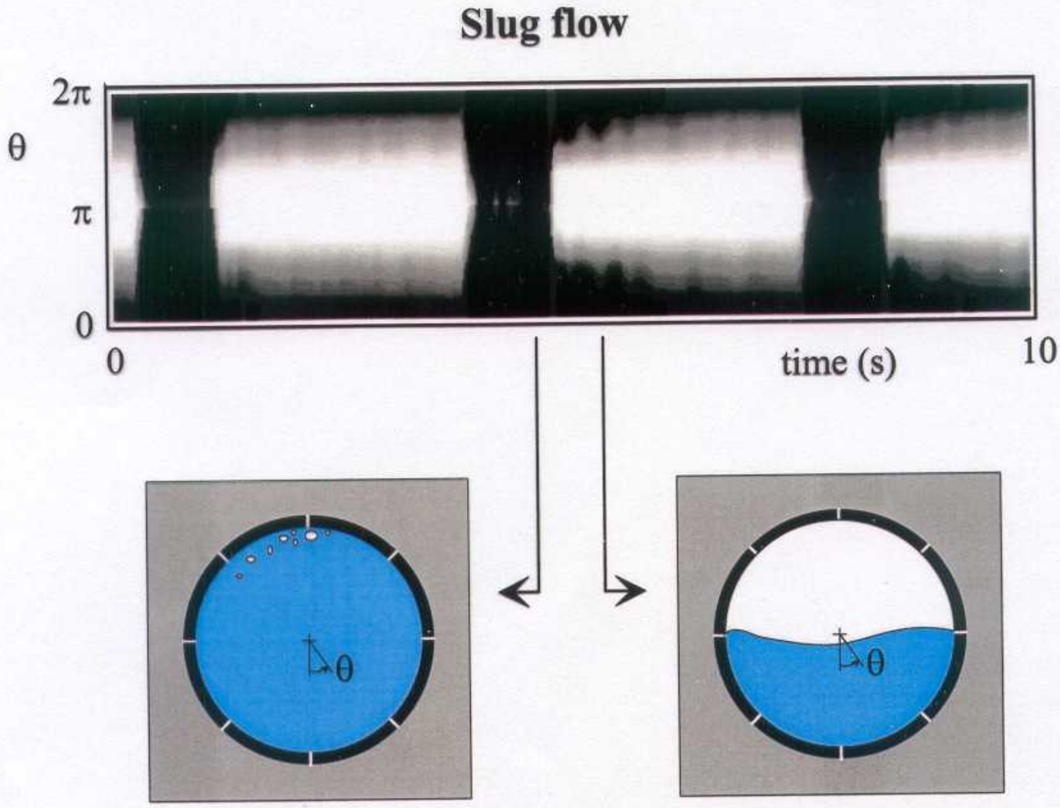

Ø INTERIEUR
12 mm

Impedance probe

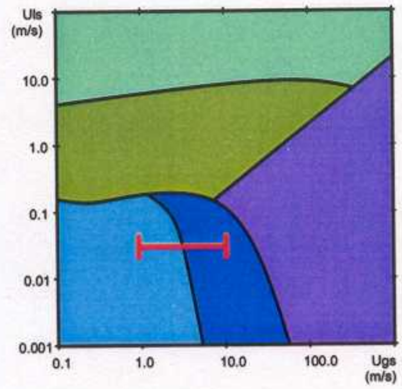
- non intrusive
- spatial and dynamic information
- easy optimization (3D simulation)



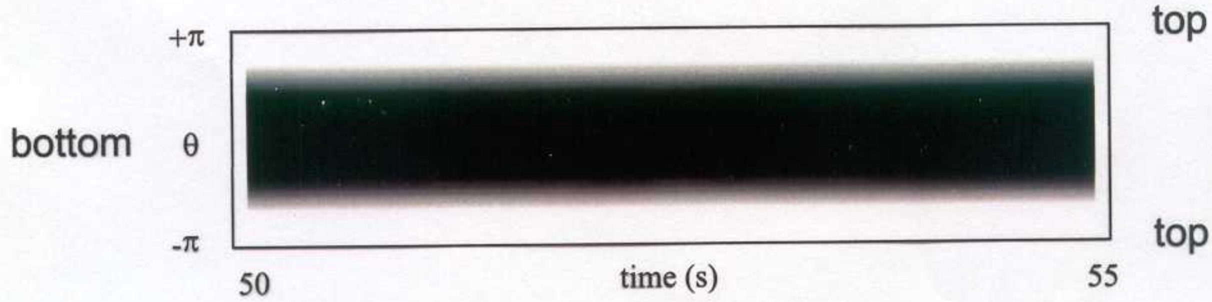
Flow monitoring (real time)

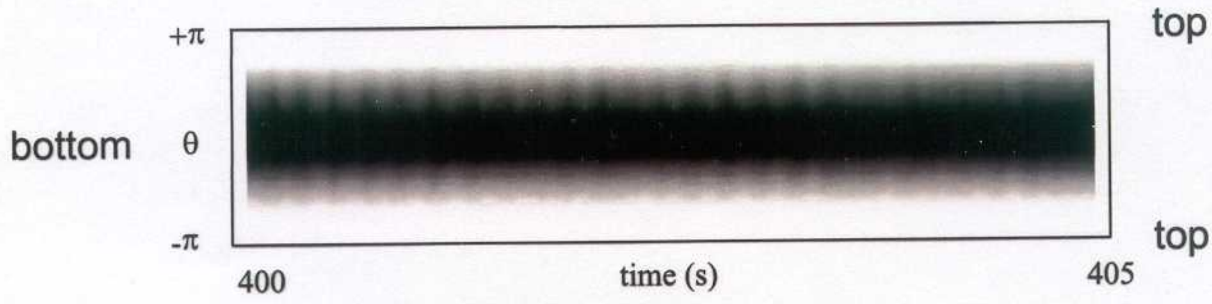


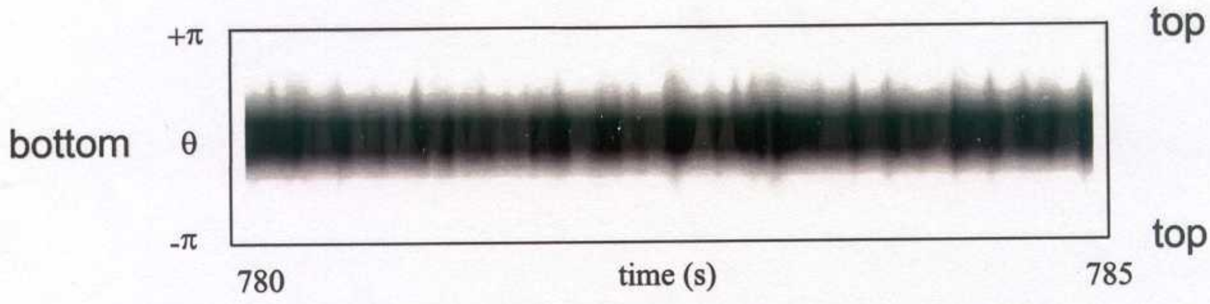
Smooth - Rugged Stratified Flow Evolution



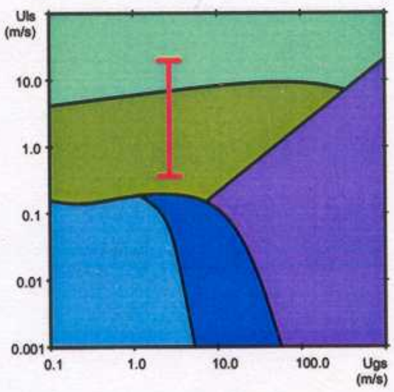
$Q_{water} = 0.5\ m^3/h$ - $Q_{air} = 10 - 60\ m^3/h$



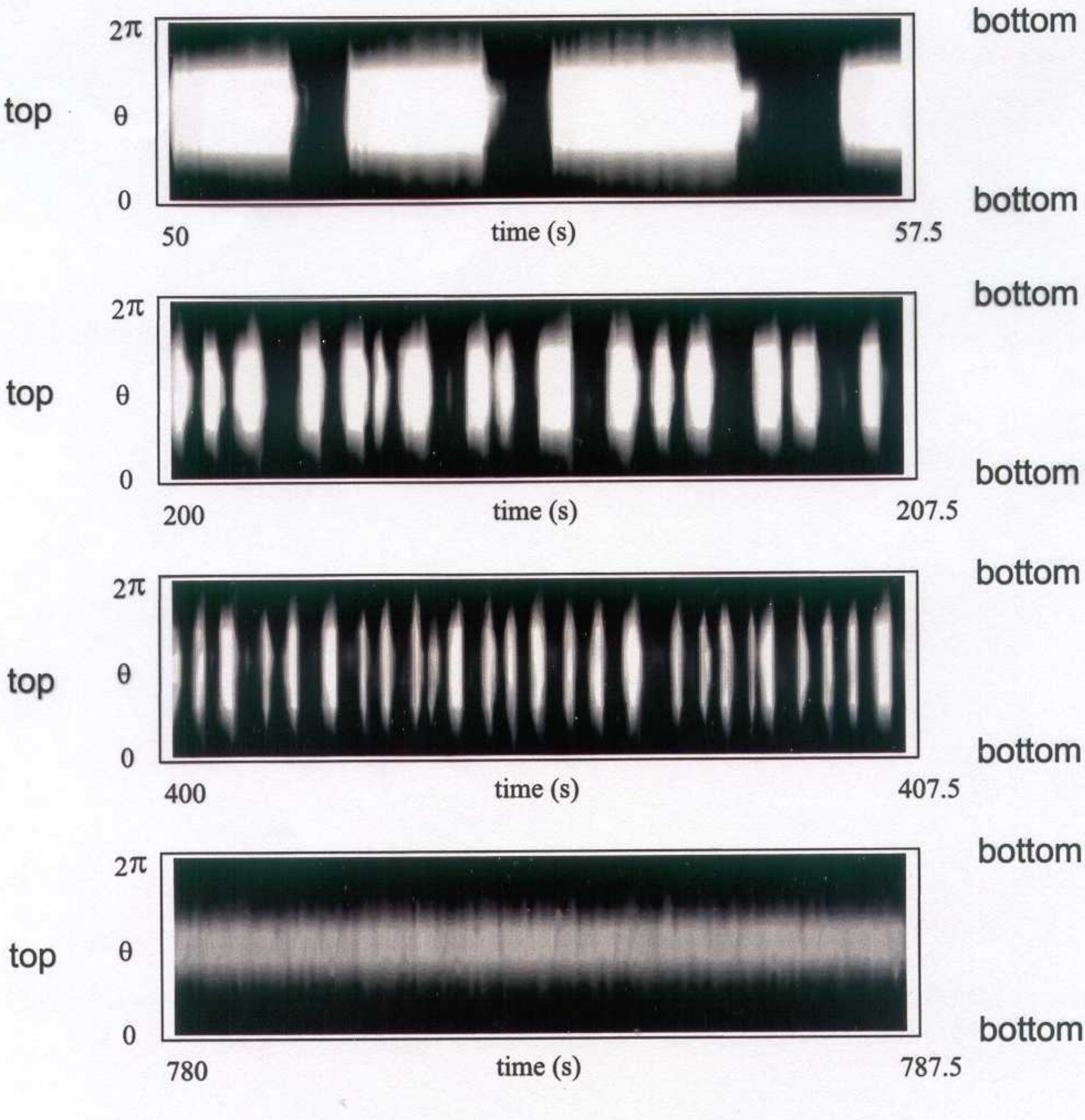




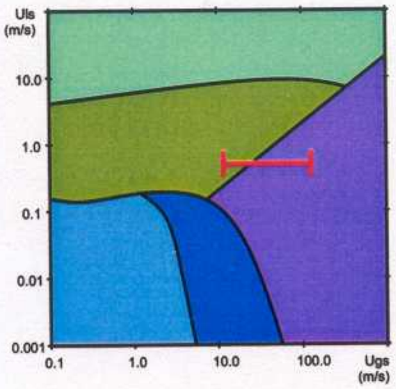
Intermittent - Bubbly Flow Evolution



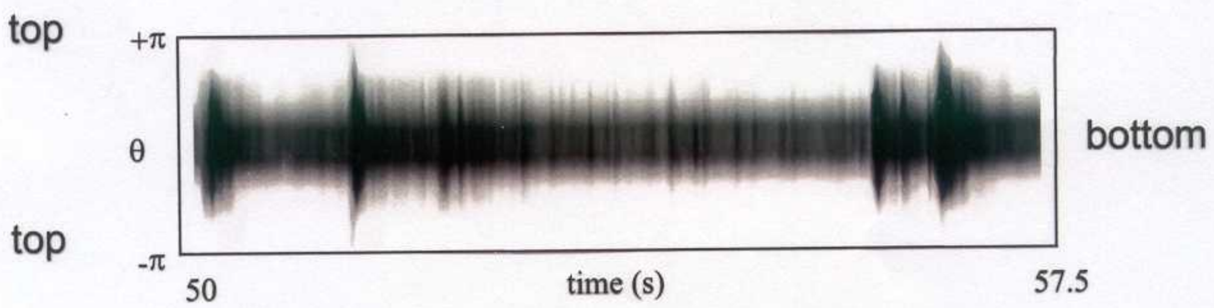
$Q_{air} = 7.5\ m^3/h$ - $Q_{water} = 5 - 50\ m^3/h$

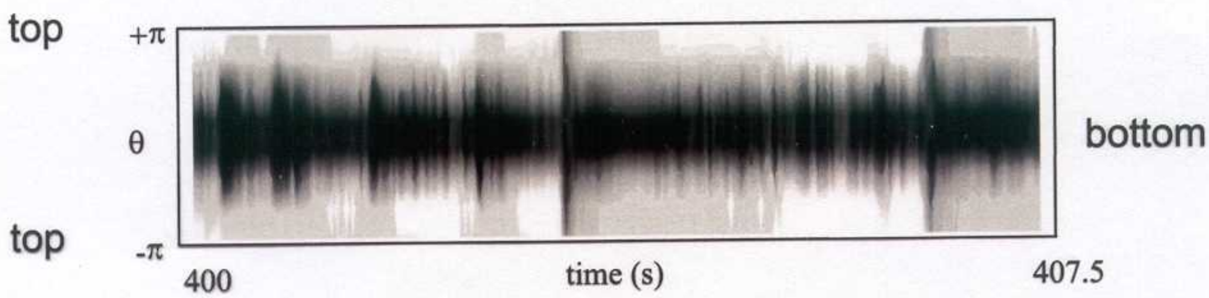


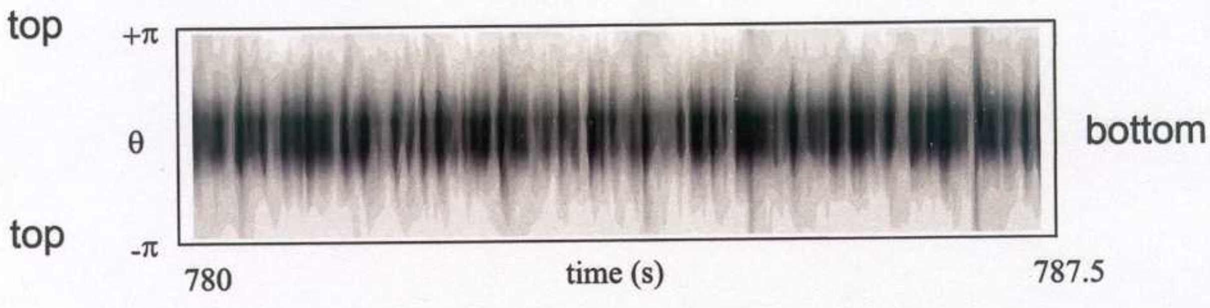
Intermittent - Annular Flow Evolution



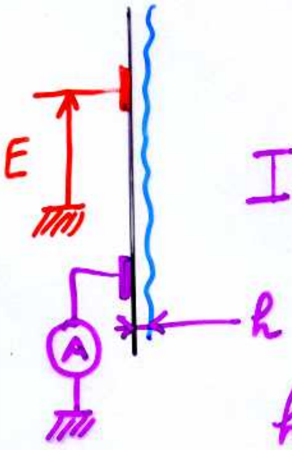
$Q_{water} = 15\ m^3/h$ - $Q_{air} = 70 - 250\ m^3/h$



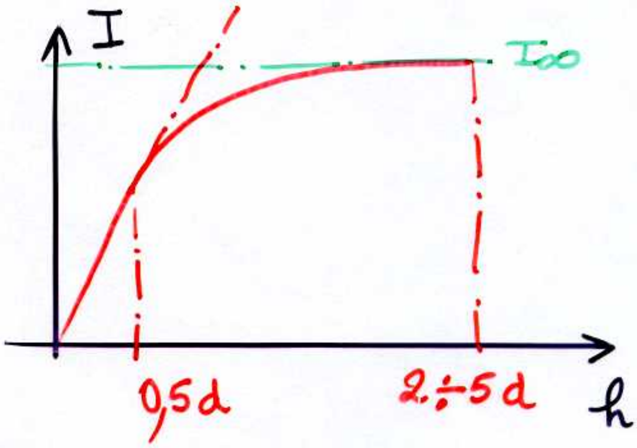




- Epaisseur de film liquide

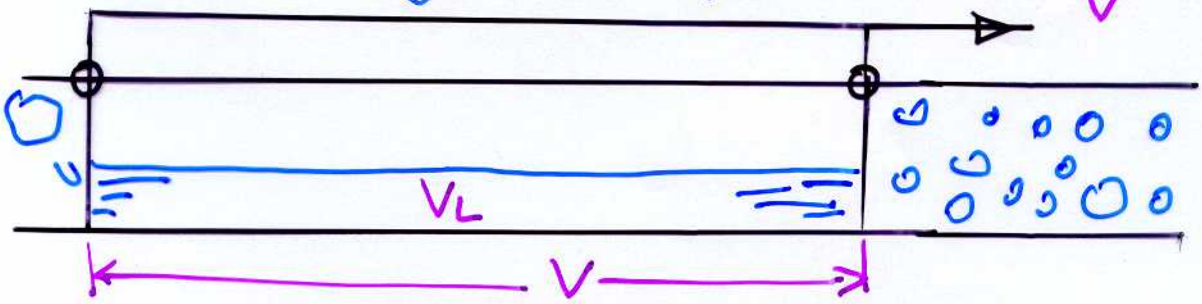


$$I = E\sigma_c \, f\left(\frac{h}{d}\right)$$

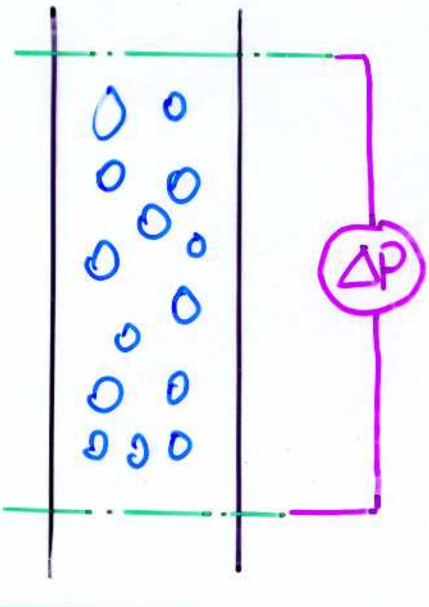


$h(t)$ dynamique

- Vannes à fermeture rapide : $R_{L3} = \dfrac{V_L}{V}$



- Méthode gravitaire



— Vitesses "faibles"

⇒ frottement et accélération → 0

$$\Delta P = \rho_m g h$$

$$\rho_m = (1 - R_{G3})\rho_L + R_{G3}\rho_G$$

LES PREMIERS MODELES SIMPLE de TAUX de VIDE

- Situations d'équilibre (établies) transitoires lents.

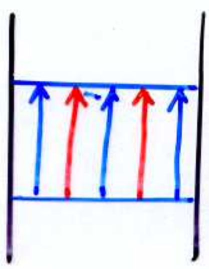
– Idéalisation de l'écoulement.

- déséquilibre mécanique $\overrightarrow{W}_G^{x} \neq \overrightarrow{W}_L^{x}$
- déséquibre thermodynamique

$$\overline{h}_L^{x} \neq h_{Lsat}(p)$$
$$\overline{h}_V^{x} \neq h_{Vsat}(p)$$

- Propriétés géométriques de l'écoulement
  – axeisymétrie, profils radiaux...

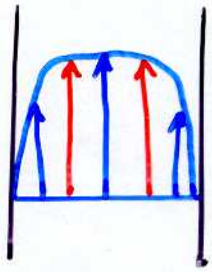
$\boxed{\text{déséquilibres imposés} \neq \text{modèle non contraint}}$



1D–1V

Homogène

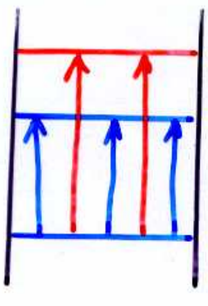
$\overrightarrow{W}_G^{x}(r) = \overrightarrow{W}_L^{x}(r) = W$



2D–1V

Bankoff

$\overrightarrow{W}_G^{x}(r) = \overrightarrow{W}_L^{x}(r) = f(r)$



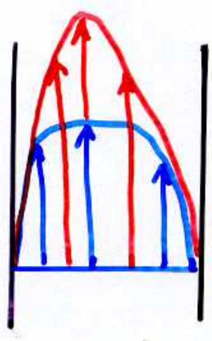
1D–2V

$\overrightarrow{W}_G^{x}(r) = \overrightarrow{W}_G^{x}$

$\overrightarrow{W}_L^{x}(r) = \overrightarrow{W}_L^{x}$

$\overrightarrow{W}_L^{x} \neq \overrightarrow{W}_G^{x}$

Wallis



2D–2V

$\overrightarrow{W}_G^{x}(r) = f(r)$

$\overrightarrow{W}_L^{x}(r) = g(r)$

Zuber – Findlay

LE MODELE HOMOGENE.

- $1D-1V$: $\overline{w_L}^x = \overline{w_G}^x = cste$

On se donne les débits : $\overline{Q_G}$ et $\overline{Q_L}$

On calcule : $\overline{R_{G2}}$ ou $\langle\!\langle \alpha \rangle\!\rangle_2$

Etablissement commun aux 4 modèles

$$\overline{Q_G} \triangleq \overline{\int_{A_G} w_G \, dA} \equiv \overline{A_G \langle w_G \rangle} = A \, \overline{R_G \langle w_G \rangle}$$

(CDM) : Commutativité des moyennes spatiales et temporelles

$$\overline{Q_G} = A \, \overline{R_G \langle w_G \rangle} = A \langle\!\langle \alpha_G \overline{w_G}^x \rangle\!\rangle$$

or $\overline{w_G}^x$ est uniforme ds la section et CDM

$$\overline{Q_G} = A \langle\!\langle \alpha_G \rangle\!\rangle \, \overline{w_G}^x = A \, \overline{R_G} \, \overline{w_G}^x \quad ⚠$$

de même pour le liquide :

$$\overline{Q_L} = A \, (1-\overline{R_G}) \, \overline{w_L}^x$$

or les vitesses sont égales

$$\frac{\overline{Q_G}}{\overline{Q_L}} = \frac{\overline{R_G}}{1-\overline{R_G}} \Rightarrow \overline{R_G} = \frac{Q_G}{Q_L + Q_G} = \frac{Q_G}{Q} \triangleq \beta$$

titre volumique

$$\boxed{\text{Modèle homogène} \quad \overline{R_G} = \beta}$$

LE MODELE de BANKOFF.

• 2D – 1 V $\begin{cases} \overline{W_L}^{x} = \overline{W_G}^{x} = w_c\left(\frac{y}{R}\right)^{\frac{1}{m}} \\ \alpha_G = \alpha_c\left(\frac{y}{R}\right)^{\frac{1}{n}} \end{cases}$

On se donne les débits : $\overline{Q_G}$ et $\overline{Q_L}$

On calcule $\overline{R_{G2}} \equiv \langle \alpha \rangle_2$

Definition des débits moyens

$$\overline{Q_G} = A \langle \alpha \overline{w_G}^{x} \rangle = A\, f(w_c, \alpha_c, m, n)$$

$$\overline{Q_L} = A \langle (1-\alpha) \overline{w_L}^{x} \rangle = A\, g(w_c, \alpha_c, m, n)$$

Calcul de

$$\langle \overline{W_L}^{x} \rangle = \langle \overline{W_G}^{x} \rangle = h(w_c, m)$$

$$\overline{R_G} = \langle \alpha \rangle = k(\alpha_c, n)$$

on élimine α_c et w_c

$$R_G = K\beta$$

$$K = \frac{2(m+n+mn)(m+n+2mn)}{(n+1)(2n+1)(m+1)(2m+1)}$$

$$K = 0{,}6 \div 1 \quad 2 \leq m, n \leq 7$$

Corrélation de Bankoff.

$$K = 0{,}71 + 0{,}00145\, p \quad (p \text{ en bar})$$

MODELE de WALLIS

- 1D – 2V $\begin{cases} \overline{W_L}^x \neq \overline{W_G}^x & \text{mais uniformes} \\ \alpha_G(r) = \alpha_G & \text{"} \end{cases}$

On se donne les débits : $\overline{Q_L}$ et $\overline{Q_G}$
On cherche : $\overline{R_{G2}}$

Définition des débits :

1/A $\overline{Q_G} = \langle \alpha \overline{W_G}^x \rangle = \overline{R_G}\, \overline{W_G}^x$

1/A $\overline{Q_L} = \langle (1-\alpha) \overline{W_L}^x \rangle = (1-\overline{R_G})\, \overline{W_L}^x$

On calcule R_G

$$\overline{R_G} = \frac{Q_G \overline{W_L}^x}{Q_L \overline{W_G}^x + Q_G \overline{W_L}^x} = \frac{\beta}{1 + \frac{(1-\overline{R_G})(\overline{W_G}^x - \overline{W_L}^x)}{J}}$$

Rappel $J = \dfrac{Q}{A} = \dfrac{Q_L + Q_G}{A}$.

Exemple : Ecoulement à bulles w_∞ Vit. bulle

$$\overline{W_G}^x - \overline{W_L}^x \approx w_\infty (1 - \overline{R_G})$$

- Corrélation pour w_∞ (D, σ, ρ_L, ρ_G, μ_L etc...)
  Clift par exemple
- Diagramme de Wallis

DIAGRAMME de WALLIS

- Définitions

- $$j_k \triangleq \alpha_k \overline{w_k}^x = \overline{X_k w_k} \quad ; \quad j = j_L + j_G$$

vitesse de dérive (vitesse relative / c du vol)

$$v_{kj} \triangleq \overline{w_k}^x - j$$

flux de dérive (flux de phase k / c du volume).

$$j_{GL} \triangleq \alpha_G (\overline{w_G}^x - j)$$

- Hypothèse 1D

$$J_{GL} = \langle j_{GL} \rangle = \overline{R_G}\,(\overline{W_G}^x - J) = (1-\overline{R_G})\,J_G - \overline{R_G}\,J_L \quad (1)$$

$$J = J_G + J_L = \overline{R_G}\,\overline{W_G}^x + (1-\overline{R_G})\,\overline{W_L}$$

$$\Longrightarrow \quad J_{GL} = \overline{R_G}\,(1-\overline{R_G})\,(\overline{W_G}^x - \overline{W_L}^x)$$

- Corrélation pour $\overline{W_G}^x - \overline{W_L}^x$ en éc à bulles

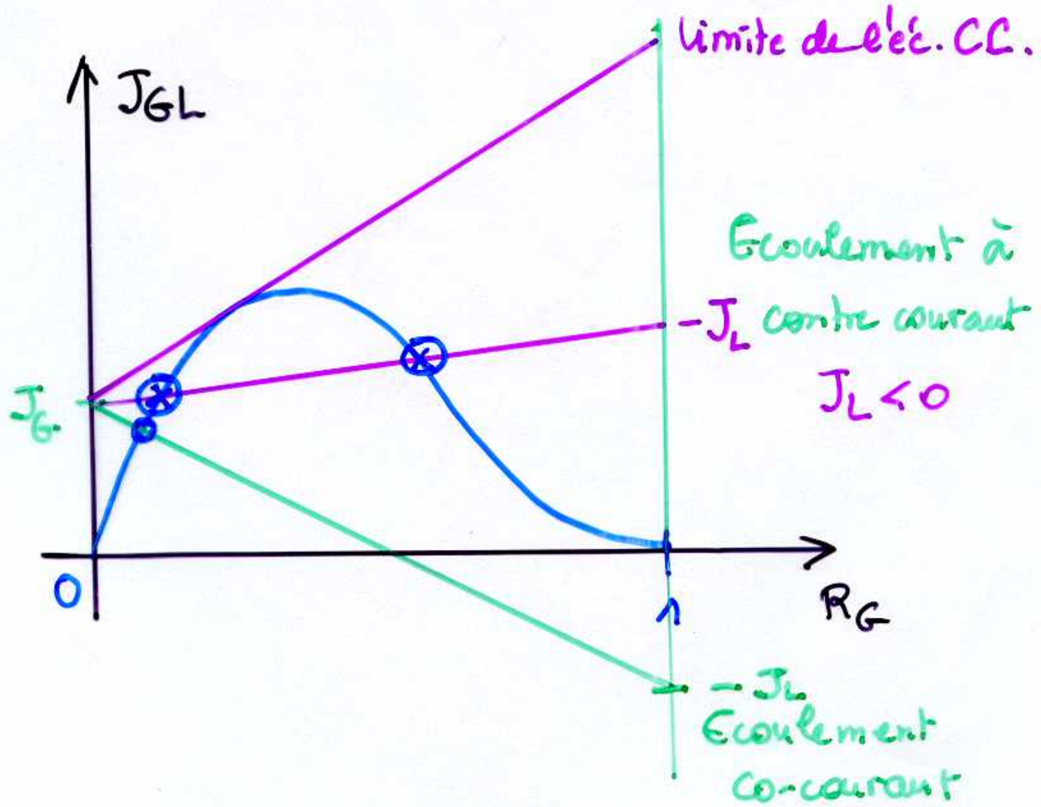
$$J_{GL} = W_\infty R_G (1-R_G)^2 \quad (2)$$

- Diagramme de Wallis

$J_{GL} = f(R_G)$

(1) droite $R_G = 0 \,;\, J_G$; $R_G = 1 \,;\, -J_L$

(2) courbe



- Ecoulement co-courant ascendant.
  - 1 seul régime
- Ecoulement à contre courant
  - 2 régimes peuvent coexister

MODELE de Zuber Findlay

- 2D – 2V
- le plus général : on se donne $\overline{Q_G}$ et $\overline{Q_L}$

  on recherche $\overline{R_{G2}}$

On part de la vitesse de dérive locale

$$\overrightarrow{W_{Gj}}^{x} \triangleq \overline{W_G}^{x} - j = (1-\alpha_G)(\overline{W_G}^{x} - \overline{W_L}^{x})$$

On moyenne sur la section le flux de dérive

$$\langle \alpha_G \overrightarrow{W_{Gj}}^{x} \rangle = \langle \alpha_G \overline{W_G}^{x} \rangle - \langle \alpha_G j \rangle$$

$$\langle \alpha_G \rangle \widetilde{w_{Gj}} = J_G - C_0 \langle \alpha_G \rangle \langle j \rangle$$

$$R_G = \frac{J_G}{C_0 J + \widetilde{w_{Gj}}}$$

$$\widetilde{w_{Gj}} \triangleq \frac{\langle \alpha \overline{W_{Gj}}^{x} \rangle}{\langle \alpha_G \rangle}$$

$$C_0 = \frac{\langle \alpha_G j \rangle}{\langle \alpha_G \rangle \langle j \rangle}$$

- dégénère sur les autres modèles
- Expériences $\longrightarrow$ corrélations par régime

$$\frac{J_G}{R_G} = FL(J) \Rightarrow C_0 \text{ et } \widetilde{w_{Gj}}$$

After Ishii
ANL Report 77-47

Le modèle de Zuber et Findlay

Ce modèle conduit à l'expression suivante du taux de vide :

$$R_G = \frac{\beta}{C_0 + \tilde{v}_{gj}/J}$$

où β est le titre volumique et $J \widehat{=} J_G + J_L$ la vitesse débitante du mélange ; l[e] paramètre de distribution C_0 et la vitesse de dérive pondérée $\tilde{v}_{gj}$ dépendent du typ[e] d'écoulement.

Les expressions suivantes peuvent être recommandées pour les conduites vertica[-]les :

wall peaking.

$$C_0 = \left(1,2 - 0,2\sqrt{\frac{\rho_G}{\rho_L}}\right)(1 - \mathrm{e}^{-18 R_G})$$

Écoulements à bulles :

$$\tilde{v}_{gj} = (C_0 - 1)J + 1,4\left[\frac{\sigma g(\rho_L - \rho_G)}{\rho_L^2}\right]^{0,25}(1 - R_G)^{1,75}$$

Écoulements à poches :

$$\tilde{v}_{gj} = (C_0 - 1)J + 0,35\left[\frac{g(\rho_L - \rho_G)D}{\rho_L}\right]^{0,5}$$

Écoulements agités :

$$\tilde{v}_{gj} = (C_0 - 1)J + 1,4\left[\frac{\sigma g(\rho_L - \rho_G)}{\rho_L^2}\right]^{0,25}$$

Écoulements annulaires :

$$\tilde{v}_{gj} = \frac{1 - R_G}{R_G + \left[\frac{1 + 75(1 - R_G)}{\sqrt{R_G}}\frac{\rho_G}{\rho_L}\right]^{0,5}}\left[J + \sqrt{\frac{(\rho_L - \rho_G)gD(1 - R_G)}{0,015\rho_L}}\right]$$

MASS FLOW RATE DETERMINATION IN TWO-PHASE FLOW: THE GRENOBLE EXPERIENCE

- EQUIPMENT
- FLOW RATE CALCULATION

EQUIPMENT

- Gammadensitometer $\longrightarrow R_{G1}$

- Venturi

(1) $M_V = k \sqrt{\rho_V \Delta p}$

k (in m^2) : coefficient obtained from a calibration in liquid single phase flow

M_V (in kg/s) ρ_V (in kg/m³) Δp (in Pa)

(2) $$\frac{1}{\rho_V} = \frac{x^2}{R_V \rho_G} + \frac{(1-x)^2}{(1-R_V)\rho_L}$$

- Turbine

(3) $M_T = \lambda \rho_T f$

λ (in m^3) : coefficient obtained from a calibration in liquid single phase flow

M_T (in kg/s) ρ_T (in kg/m³) f (in s^{-1})

(4) $$\frac{1}{\rho_T} = \frac{x^2}{R_T \rho_G} + \frac{(1-x)^2}{(1-R_T)\rho_L}$$ (Popper, 1961; Rouhani, 1964)

Method # 1 : "Homogeneous model"

- Equipment :

Gammadensitometer	$\longrightarrow$	R_{G1}
Venturi	$\longrightarrow$	Δp
Turbine	$\longrightarrow$	f

- Hypotheses :

  A. $R_{G2} \equiv R_{G1}$

  B. $R_V \equiv R_T \equiv R_{G2}$

  C. Homogeneous model

- Flow rate calculation : $\quad B : (2) \& (4) \rightarrow \rho_V \equiv \rho_T$

$$\rho_V \equiv \rho_T = R_{G2}\,\rho_G + (1 - R_{G2})\,\rho_L$$

$$(A) \rightarrow \rho_V \equiv \rho_T = R_{G1}\,\rho_G + (1 - R_{G1})\,\rho_L$$

$$(1) \rightarrow M_V \qquad (3) \rightarrow M_T$$

$$C \rightarrow \frac{1}{\rho_V} \equiv \frac{1}{\rho_T} \equiv \frac{x}{\rho_G} + \frac{(1-x)}{\rho_L} \longrightarrow x$$

- Consistency check : $\qquad M_V \equiv M_T$

- Application :

  Rod bundle blowdown (Ω)

Method #2: "Venturi - turbine"

- **Equipment:**

  Venturi $\longrightarrow$ Δp

  Turbine $\longrightarrow$ f

- **Hypotheses:**

  A. $\rho_V \equiv \rho_T \mathrel{\hat{=}} \rho$

- **Flow rate calculation:**

$$M_V \equiv M_T \mathrel{\hat{=}} M$$

$$(1) \,\&\, (3) \longrightarrow \quad M = \frac{k^2 \Delta p}{\lambda f}$$

If B. Homogeneous model $\longrightarrow$ $\dfrac{1}{\rho} = \dfrac{x}{\rho_G} + \dfrac{(1-x)}{\rho_L}$

- **Application:**

  Rod bundle blowdown (Ω)

TURBINE FLOWMETERS

DIAMETER :

12 TO 154 MM

BLADE MATERIAL :

STAINLESS STEEL
TITANIUM

MAXIMUM ROTATIONAL SPEED :

12 MM DIA : 120 000 RPM
154 MM DIA : 15 000 RPM

MAXIMUM ROTATIONAL ACCELERATION :

600 000 REVOLUTIONS/S^2

MAXIMUM OPERATING TEMPERATURE :

780°C
900°C FOR SHORT PERIODS

DYNAMIC RANGE :

0.05 TO 225 M/S (WATER ; 46 MM DIA)

WASH	36 / 26	Measurement of the INTEGRAL specific area $\Gamma(t)$ in pipe flows

Methods compared :

- photographic (bubble diameter measurements)
- chemical (oxidation of sodium sulfite into sodium sulfate)
- optical (light attenuation)

WASH	36 / 27	Photographic method

- Advantages :
  - instantaneous picture
- Disadvantages :
  - limited to bubbly or droplet flow
  - 2 D picture of the flow near the wall
  - very tedious

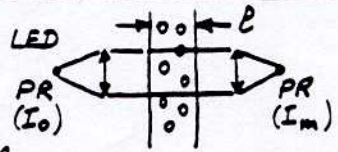
WASH	36 / 28	Chemical method

- Advantages :
  - does not depend on flow pattern
- Disadvantages :
  - limited to steady state flow
  - limited to well defined contactors
  - requires special fluids (aqueous solution of sodium sulfite, oxygen and Co^{++} as a catalyst)
  - very lengthy (concentration determination)
  - requires a calibration set-up

WASH 36 / 31

Optical technique

- Advantages:
  - simple
  - gives instantaneous values



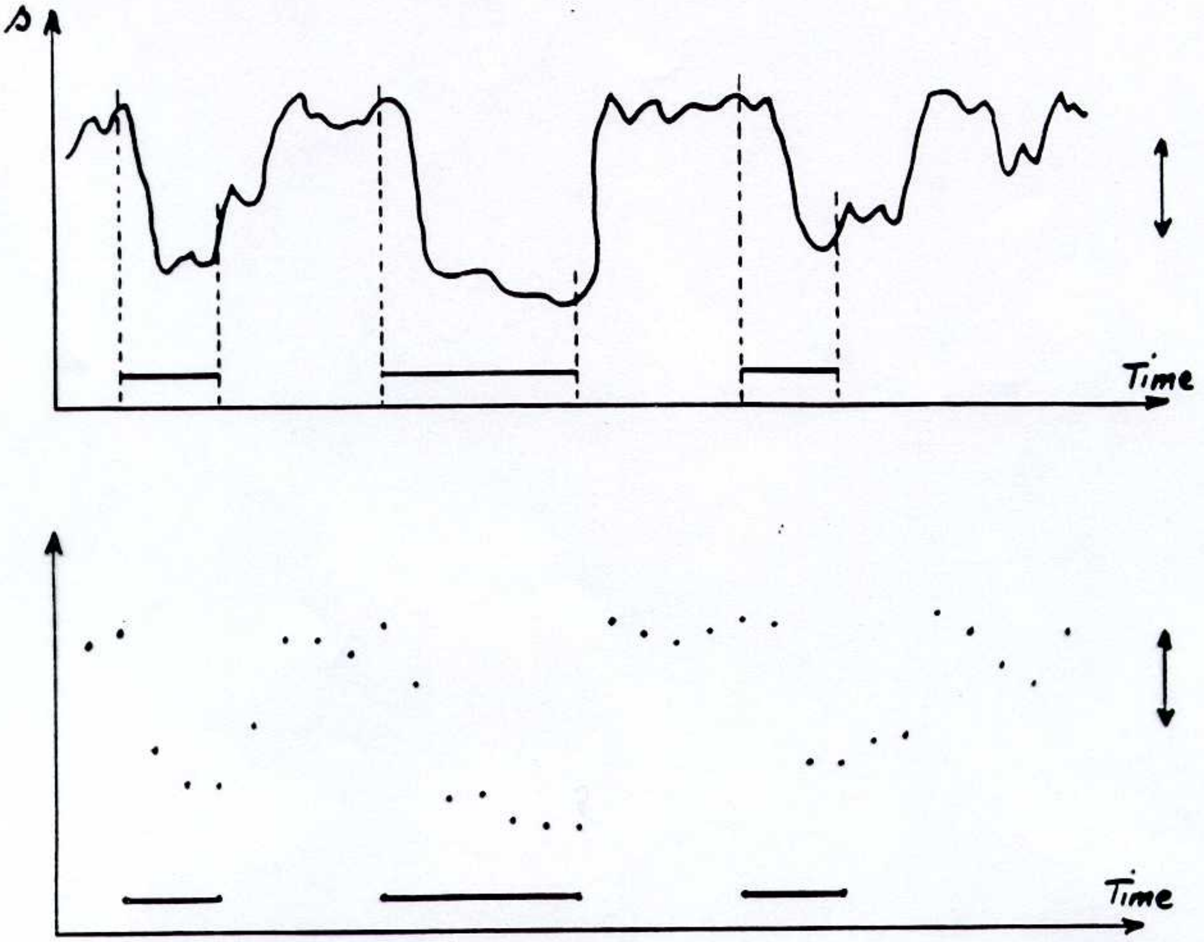
$$\Gamma = \frac{4}{\ell} \ln \frac{I_o}{I_m}$$

- Disadvantages:
  - limited to bubbly or droplet flow
  - limited to homogeneous dispersions

LED: light emitting diode
PR: photoreceiver
I_o: emitted intensity
I_m: received intensity

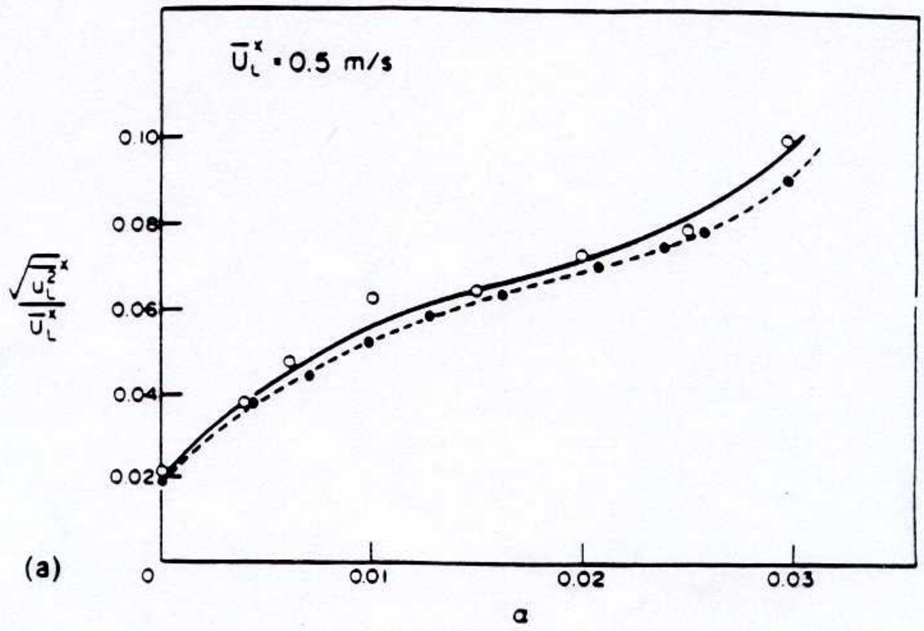
THERMAL ANEMOMETER SIGNAL PROCESSING

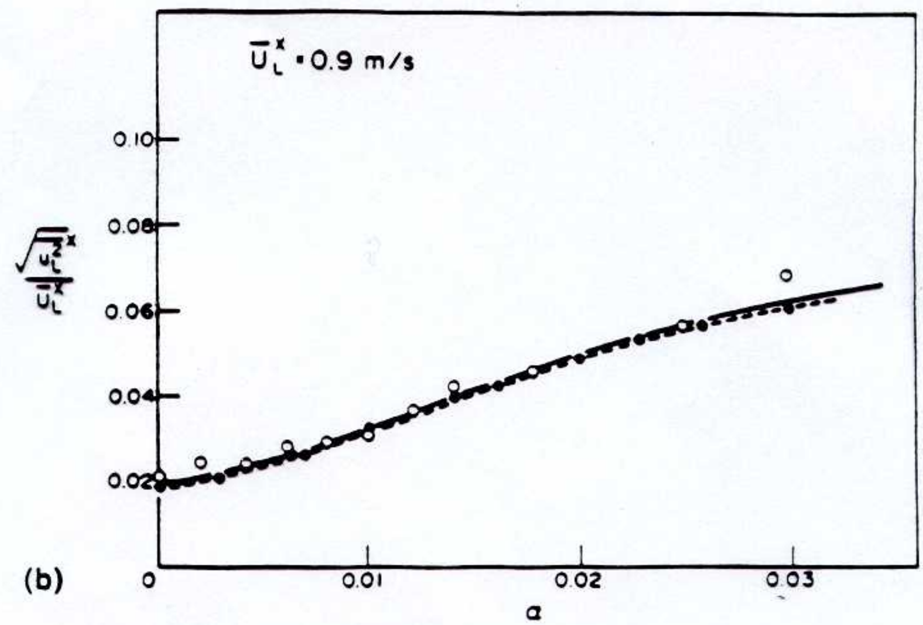
- AMPLITUDE DISCRIMINATION : RESCH



- OTHER TECHNIQUES :
  - PDF splitting (DELHAYE, GALAUP, HERRINGE)
  - Threshold on the signal (JONES)
  - Threshold on the signal derivative (DUKLER)

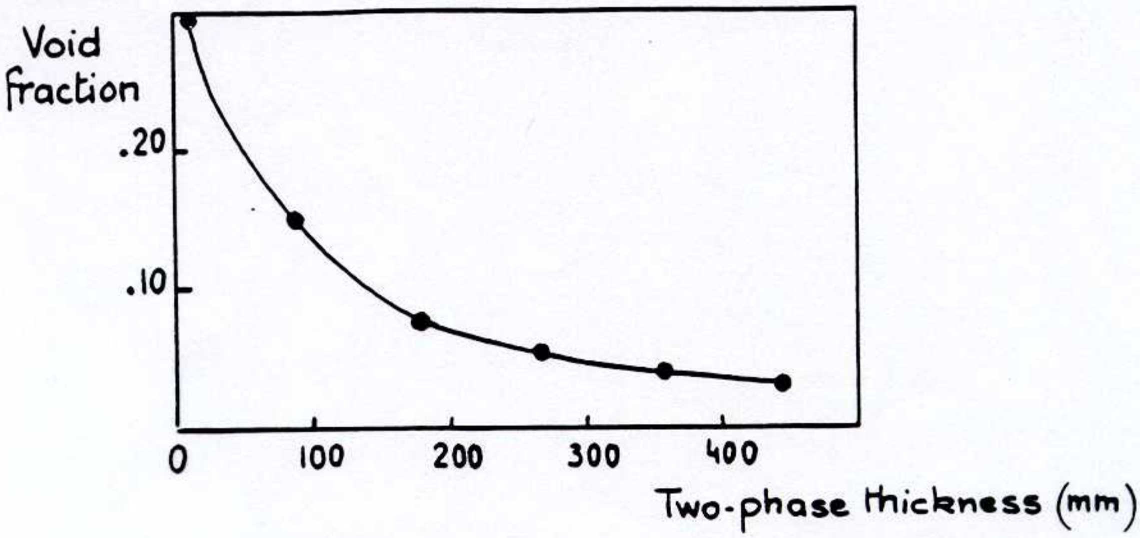
- GIVES :
  - Local void fraction α_G
  - Instantaneous liquid velocity w_L


$\overline{U}_L^x$ = 0.5 m/s
0.10
0.08
0.06
0.04
0.02
(a)
0
0.01
0.02
0.03
α


$\overline{U}_L^x$ = 0.9 m/s
0.10
0.08
0.06
0.04
0.02
(b)
0
0.01
0.02
0.03
α

MARIÉ, 1983

Limitations



See Marié & Lance (1984)