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SOME METHODS TO ESTIMATE THE THERMAL CONDUCTIVITY OF INSULATING MEDIA - APPLICATION TO THE CHARACTERIZATION OF FLUIDS IN LAMINAR COUETTE FLOW.

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ABSTRACT

In first part, the method described here is to measure thermal conductivity of super insulating materials. The principle is based on a simple transient experiment and a single temperature measurement. The main idea is to control the heat flux diffusion in the sample by adjunction of a semi-infinite highly conductive medium.

In second part, we present a transient method to estimate thermophysical properties and viscosity of fluid in Couette flow. It is an extension of the previous method.

INTRODUCTION

Designing an experimental device to estimate thermophysical conductive properties of superinsulating materials is generally difficult.

The use of the transient flash method (see Parker and al , 1961; Degiovanni, 1977) to measure thermal diffusivity is also difficult due to the influence of heat losses around the sample. Some authors (see Martin et al, 1994) have tried to improve the experiment by adding 2 metal plates on either side of the sample. However, the experiment becomes more complicated and the influence of the lateral heat losses is only attenuated.

The popular hot wire method (see Carslaw and Jaeger, 1959) is easier to implement. However, even if the cylindrical semi-infinite medium assumption avoids the problem of considering heat losses and at medium faces, some loss effects are possible at the ends of the wire. Moreover, large temperature gradients around the wire, due to the geometry, can introduce some estimation errors in the case of non-linear heat transfer.

The new device proposed here tries to combine all advantages of previous methods. The main idea is to control the heat flux diffusion inside the insulating sample by addition of a highly conductive metal support. No regulated heat sink and fluxmeter is then needed. A probe similar to the hot wire system is used to measure only one temperature evolution on a planar heating device. Therefore, the transfer becomes quite 1D and steady, even if a model considering 2D geometry and transient state is necessary.

In second part, an extension of this method is proposed for thermal characterization of fluid in Couette flow. The main difficulty is to solve the transient heat transfer trough the multilayer system (see David and al, 1993; Soliman and al, 1967; Osizik). We present in this paper an extension of quadripole formalism.

NOMENCLATURE

A, B, C, D	Quadripole elements
Q	Excitation heat flux
Rc	Contact resistance
T	Temperature
a	Thermal diffusivity
x, y, z	Spatial coordinate
p	Laplace parameter
t	Time
E	Thermal effusivity
b, L	Lateral dimensions

e	Thickness
λ, τ	Thermal conductivity
ψ, φ	Laplace-Fourier flux
θ, τ	Laplace-Fourier temperature
ρc_p	Volumetric thermal capacity
α, ω	Fourier parameter
i	indice relative to i-layer

INSULATING MEDIA CHARACTERIZATION

Modelling

The device described in figure 1 can be modeled using the following system:

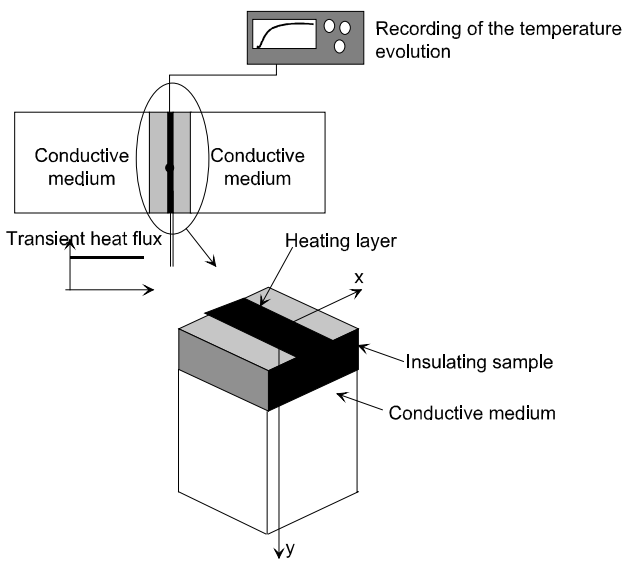

Figure 1-a: Scheme of the device

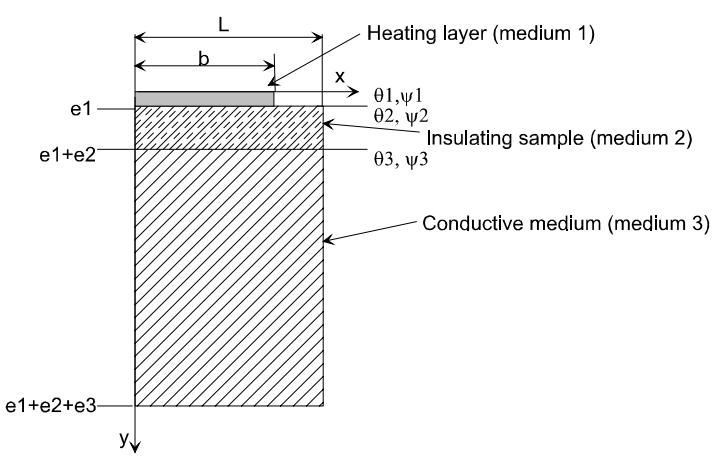

Figure 1-b : Main geometrical parameters of the device

Transfer inside the heating layer (medium 1):

This layer is metallic and considered to be infinitely thin. Thus temperature distribution is assumed to be uniform versus z-direction. It yields then:

$$(\rho c_p)_1 e_1 \frac{\partial T_1^*}{\partial t} = Q + \Phi_2(z = e_1) \qquad (1)$$

Where Q is the Joule effect heat flux and $\Phi_2(z = e_1)$ describes the heat flux penetrating inside the insulating sample (medium 2).

Transfer inside the insulating sample (medium 2) and inside the conductive medium (medium 3):

Heat transfer is here assumed to be purely conductive and the sample isotropic. It yields:

$$\frac{\partial^2 T_i^*}{\partial x^2} + \frac{\partial^2 T_i^*}{\partial y^2} = \frac{1}{a_i}\frac{\partial T_i^*}{\partial t} \quad \text{i} = 2,3 \qquad (2)$$

with flux and temperature continuity at interfaces between media 1and 2, and media 2 and 3.

Initially, the whole system is assumed to be at uniform temperature *To*. A new variable is then considered such as $T_i = T_i^* - To$.

To write the previous system in a less complex form, Laplace and Fourier transforms yields:

$$\theta(\alpha_n, y, p) = \int_0^L \int_0^\infty T(x,y,t) e^{-pt} \cos(\alpha_n x)\, dt dx$$
$$\text{and } \alpha_n^2 = \frac{n\pi}{L} \qquad (3)$$

Then equation (2) becomes an ordinary differential equation:

$$\frac{d^2\theta_i}{dy^2} = \left(\frac{p}{a_i} + \alpha_n^2\right)\theta_i \qquad (4)$$

with heat flux definition such as:

$$\psi_i(\alpha_n, p, y) = -\lambda_i \frac{d\theta_i(\alpha_n, p, y)}{dy} \qquad (5)$$

Expressions (4) and (5) are then equivalent to a quadripole presentation (see Batsale et al, 1994) such as:

$$\frac{d}{dy}\begin{bmatrix}\theta_i(\alpha_n, p, y)\\ \psi_i(\alpha_n, p, y)\end{bmatrix} = \begin{bmatrix}0 & -1/\lambda_i\\ -(\rho c_p)_i\, p + \alpha_n^2 & 0\end{bmatrix}\begin{bmatrix}\theta_i(\alpha_n, p, y)\\ \psi_i(\alpha_n, p, y)\end{bmatrix} \qquad (6)$$

The solution of (6) gives a simple relationship between temperature and flux vector at boundaries of each medium such as:

$$\begin{bmatrix} \theta_i(\alpha_n, p, \underset{j=1}{\overset{i-1}{}} e_j) \\ \psi_i(\alpha_n, p, \underset{j=1}{\overset{i-1}{}} e_j) \end{bmatrix} = \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} \theta_i(\alpha_n, p, \underset{j=1}{\overset{i}{}} e_j) \\ \psi_i(\alpha_n, p, \underset{j=1}{\overset{i}{}} e_j) \end{bmatrix} \quad (7\text{-a})$$

with

$$A_i = D_i = \cosh(K_i e_i) \quad B_i = \frac{\sinh(K_i e_i)}{\lambda_i K_i}$$
$$C_i = \lambda_i K_i \sinh(K_i e_i) \quad \text{and } K_i = \sqrt{\frac{p}{a_i} + \alpha_n^2} \quad (7\text{-b})$$

Medium 3 is considered as semi-infinite so that the transformed temperature distribution is under the form:

$$\theta_3(\alpha_n, p, y) = \theta_3(\alpha_n, p, e_1 + e_2) exp(-K_3) y \quad (8)$$

Then it yields the following:

$$\theta_3(\alpha_n, p, z) = \frac{1}{\lambda_3 K_3} exp(-K_3 z)$$
$$and\ \psi_3(\alpha_n, p, z)\big|_{z=e_1+e_2} = \lambda_3 K_3 \theta_3(\alpha_n, p, e_1 + e_2) \quad (9)$$

The entire system can be described in transformed space as:

$$\begin{bmatrix} \theta_1(\alpha_n, p, 0) \\ \Psi_1(\alpha_n, p, 0) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ (\rho c_p)_1 e_1 p & 1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} \theta_3(\alpha_n, p, e_1 + e_2) \\ \Psi_3 = \lambda_3 K_3 \theta_3(\alpha_n, p, e_1 + e_2) \end{bmatrix} \quad (10)$$

The transformed temperature measured on the heating plate is then:

$$\theta_1(\alpha_n, p, 0) = \frac{\{A_2 + B_2 \lambda_3 K_3\} \psi_1(\alpha_n, p, 0)}{C_2 + A_2 (\rho c_p)_1 e_1 p + \lambda_3 K_3 \{B_2 (\rho c_p)_1 e_1 p + D_2\}} \quad (11)$$

Such an expression is rather complex and can be inverted in real space by numerical computation. Nevertheless, some asymptotic expansions can give some insights to the physical behavior of the system.

Physical behavior of the system throught asymptotic assumption

- **Asymptotic behavior of (11) when ($(\rho c_p)_1 e_1 = 0$ and $\lambda_3 \to \infty$)**

Expression (11) yields then:

$$\theta_1(\alpha_n, p, 0) = \frac{th(\alpha_n e_2)}{\lambda_2 \alpha_n} \frac{Qb\, sin(\alpha_n b)}{p \alpha_n} \quad (12)$$

In real space a relationship between the temperature measured at the center of the plate (x=0, y=0) gives:

$$T(0,0,t) = \frac{e_2 Qb}{\lambda_2 L} + \frac{2Qb}{\lambda_2 L} \sum_{n=1}^{\infty} \frac{th(\alpha_n e_2)}{b \alpha_n} \frac{sin(\alpha_n b)}{\alpha_n} = R_c Q \quad (13)$$

- Where *Rc* is the constriction resistance between the heating plate and the semi-infinite cool plate. The definition of *Rc* is then :

$$Rc = \frac{e_2 b}{\lambda_2 L} + \frac{2b}{\lambda_2 L} \sum_{n=1}^{\infty} \frac{th(\alpha_n e_2)}{b \alpha_n} \frac{sin(\alpha_n b)}{\alpha_n} \quad (14)$$

- $\lambda_3 \to \infty$ is assumed to be equivalent to Dirichlet zero temperature condition at *z=e1+e2+e3* depth.

- **Asymptotic behavior of (11) when ($(\rho c_p)_1 e_1 = 0$ and $(\rho c_p)_2 e_2 = 0$)**

$$\theta_1(\alpha_n, p, 0) = \frac{1}{\sqrt{\lambda_3 (\rho c_p)_3} \sqrt{p}} \frac{Qb\, sin(\alpha_n b)}{p \alpha_n} + \frac{th(\alpha_n e_2)}{\lambda_2 \alpha_n} \frac{Qb\, sin(\alpha_n b)}{p \alpha_n} \quad (15)$$

In real space, a relationship between the temperature measured at the center of the plate (*x=0, y=0*) gives:

$$T(0,0,t) = \frac{Qb}{L\sqrt{\pi}\sqrt{\lambda_3 (\rho c_p)_3}} \sqrt{t} + RcQ \quad (16)$$

Such an approximated expression as (16) is more convenient to understand the physical evolution of temperature *T(x=0,y=0,t)* (see an example of comparison between expression (11) and (16) on figure 2).

The first term depends only on the properties of medium 3. The second term (constant) depends only on thermal conductivity λ_2 and geometrical parameters

A first simple estimation method is deduced:

* Estimation of $\frac{Q}{\sqrt{\lambda_3 (\rho c_p)_3}}$ with the slope versus $\sqrt{t}$ (see figure 2).

* Estimation of *RcQ* with the origin ordinate (extrapolated).

* The value of $(\rho c_p)_2$ is fixed at $(\rho c_p)_1$ to begin the numerical estimation.

Since the Joule effect energy is estimated by electrical measurement on the heating resistance, estimation of effusivity $\sqrt{\lambda_3 (\rho c_p)_3}$ of medium 3 is a good way to verify the conservation of the heat flow inside the system.

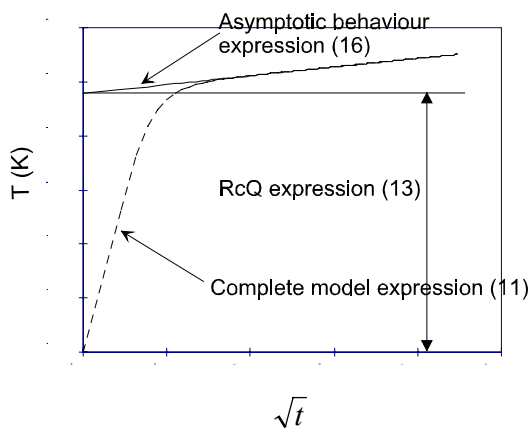

Figure 2: Example of comparison between expression (11) and (16).

This non dependence between thermophysical properties of media 2 and 3 can constitute the basic step to implement a classical numerical estimation method which minimize the norm between experimental values and exact expression (11) (see Beck, 1977). We have used a Nelder Mead minimization algorithm (see Press and al, 1986).

Experiment and result

Description of the device:

The scheme of the device is given on figure 1.

The heating probe is made with two thin foil resistance (Minco type) in which a K-type thermocouple is inserted to measure the temperature evolution of the probe. An electric generator supplies a step power excitation to the probe. The thermocouple signal is recorded on a digital oscilloscope.

The only precaution with the samples is to respect the size, parallelism and symmetry.

10-cm thick brass cylinder is used as a conductive semi infinite medium.

The validation of the device has been made using other classical methods (such as hot wire, hot plane,...).

The material used is a sample of furnace thermal insulation: Isosilikat (or Calsil).

	Hot Wire method	constructor data	**our method**
λ *(W/mK)*	0.086	0.088	**0.087**
$(\rho c_p)_2$ *(J.m^{-3}.K^{-1})*		2.33 10^5	**2.69 10^5**
E_3		2.32 10^4	**2.23 10^4**

We have observed that the rough estimation from the expression is very accurate.

Calculation of the constriction resistance *Rc* (14), gives an excellent first estimation of the thermal conductivity λ_2. In the proposed case, we obtain λ_2=0.087 W/mK. We begin the numerical estimation with this first value.

Study of measurement noise influence :

This problem can be studied with the linear least square approach (Beck et Arnold, 1977). The measurement temperature $T(t)$ is linked to real temperature $T(t)$ by the following expression :

$$T(t) = T(t) + e_T(t) \tag{17}$$

Where $e_T(t)$ is a random variable called « measurement error ». The mean value is assumed to be zero and stantard deviation to be constant for each t considered, such as (from expression (16)).

$$\begin{bmatrix} \hat{T}_1 \\ . \\ . \\ . \\ \hat{T}_n \end{bmatrix} = \begin{bmatrix} \sqrt{t_1} & 1 \\ . & . \\ . & . \\ . & . \\ \sqrt{t_n} & 1 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} = [X] \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} \tag{18}$$

Where [X] is the sensitive matrix and :

$$\beta_1 = \frac{Qb^2}{R^2\sqrt{\pi}\sqrt{\lambda_3(\rho c_p)_3}} \tag{19}$$

$$\beta_2 = RcQ$$

The optimal estimation is then :

$$\hat{\beta} = ([X]^T[X])^{-1}[X]^T\hat{T} \text{ with } \hat{\beta} = [\beta_1, \beta_2]^T \tag{20}$$

The estimation parameters vector can be written : $\beta = \beta + e_\beta$, where β is the real parametres vector and e_β is « the estimation parameters error »

Then e_β is linked to e_T by the relationship :

$$\text{cov}[e_\beta] = ([X]^T[X])^{-1}\sigma^2 \tag{21}$$

with X sensitivities matrix and σ stantard deviation on noise measurement :

$$\text{cov}[e_T] = \sigma^2[I] \tag{22}$$

With linear expression (16), we obtain the covariance matrix (figure 4) :

$$\text{cov}\begin{bmatrix} e_{\beta_1} \\ e_{\beta_2} \end{bmatrix} = \begin{bmatrix} 2.65\,10^{-5} & -10^{-3} \\ -10^{-3} & 4.02\,10^{-2} \end{bmatrix} \tag{23}$$

These values indicate a very good occuracy. So we can estimate parameters but we can also know the estimation error on these parameters. Therefore slight systematic errors can occur with the determination of the other remaining thermophysical properties such as λ_2, ρc_2, etc …

Remarks:

* Limitations relative to thermal contact resistance:

One of the main assumptions here is to neglect the thermal contact resistance between layers 1, 2 and 3. This induces a limitation with the samples to be measured. One criterion can be established:

$$\frac{e_2}{\lambda_2} >> 10^{-4}\ \mathrm{W}^{-1} m^2 K \qquad (24)$$

* Choice of the sizes

In order to fit with the previous assumption (adiabatic on lateral faces), it is important that the dimensions of the system be $L - b >> e_2$ and $e_3 >> L$.

CHARACTERIZATION OF FLUIDS IN COUETTE FLOW

We present here an extension of our method to the characterization of fluid in Couette flow. The conductive media is now a cylinder, which shear the fluid and impose a fixed temperature at the interface fluid – conductive media.

Scheme of the experimental device is given by figure 3.

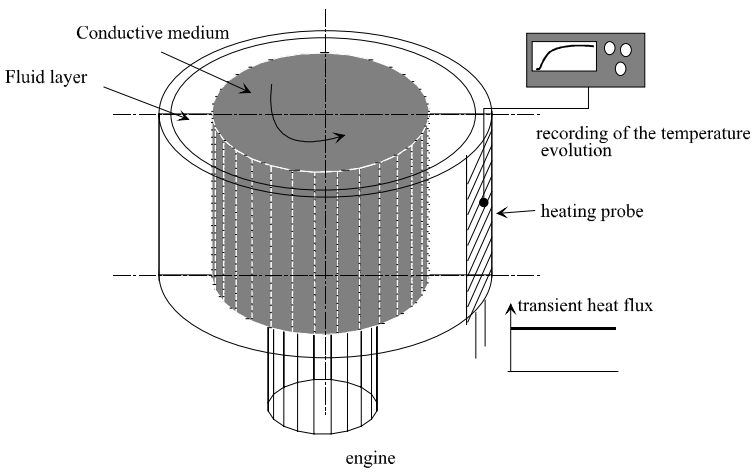

Figure 3: Experimental device for the characterization of fluid

Fluid is inserted between a polyamide layer and a conductive cylinder. The heating probe is made with two thin foil resistance (MINCO type) in which a K-type thermocouple is inserted to measure the temperature evolution of the probe. An electric generator supplies a step power excitation to the probe. The thermocouple signal is recorded on a digital oscilloscope.

Modeling

Fluid in plug flow

In first case, we model the transient heat transfer through a fluid in plug flow (figure 4). We assume to be in Cartesian coordinates *(L>>e)*. Heat transfer is here assumed to be purely conductive and the sample isotropic. We neglect viscosity effect. It yields:

$$\frac{\partial^2 T^*}{\partial y^2} + \frac{\partial^2 T^*}{\partial x^2} + \frac{V}{a}\frac{\partial T^*}{\partial x} = \frac{1}{a}\frac{\partial T^*}{\partial t} \qquad (25)$$

with flux and temperature continuity at interfaces between different layers.

Initially, the whole system is assumed to be at uniform temperature *To*. A new variable is considered $T_i = T_i^* - To$.

Boundary conditions are given by:

- Temperature and flux periodicity at *x=0* and *x=L*
- $\lambda \left.\frac{\partial T}{\partial y}\right|_{y=0} = \begin{cases} Q \text{ if } 0 < x < b \\ 0 \text{ if } b < x < L \end{cases}$
- *T(e)=0*

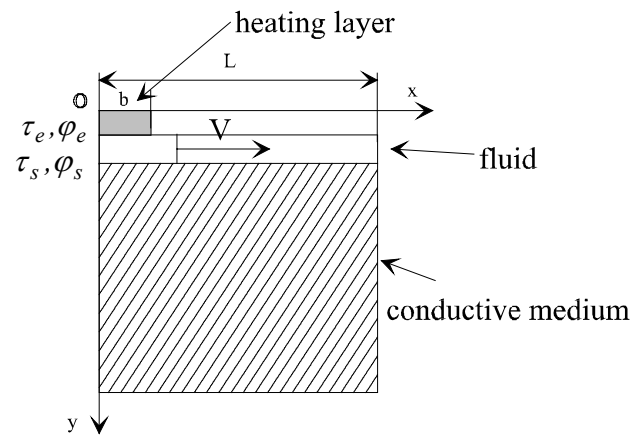

Figure 4: main geometrical parameters for a fluid in plug flow

To write the previous system in a less complex form, Laplace and Fourier transforms yields:

$$\tau(\alpha_n, y) = \int_0^L T(x,y) e^{-pt} e^{-j\omega_n x} dx \qquad (26)$$

The equation 18 becomes:

$$\frac{d^2\tau}{dy^2} = \left(\frac{p}{a} + \omega_n^2 + \frac{j\omega_n V}{a}\right)\tau \text{ and } \omega_n L = 2n\pi \qquad (27)$$

Using quadripole formalism, it becomes a simple relationship between flux and temperature:

$$\begin{bmatrix} \tau(p,\omega_n,y=0) \\ \varphi(p,\omega_n,y=0) \end{bmatrix} = \begin{bmatrix} A_n & B_n \\ C_n & D_n \end{bmatrix} \begin{bmatrix} \tau(p,\omega_n,y=e) \\ \varphi(p,\omega_n,y=e) \end{bmatrix} \qquad (28)$$

where

$$A_n = D_n = cosh(K_n e) \quad B_n = \frac{sinh(K_n e)}{\lambda K_n}$$

$$C_n = \lambda K_n\, sinh(K_n e) \quad \text{et } K_n = \sqrt{\frac{p}{a} + \omega_n^2 + \frac{j\omega_n V}{a}}$$

Considering boundary conditions, it yields the expression of temperature at *y=0*:

$$\tau(p,\omega_n,0) = \frac{B_n \varphi(p,\omega_n,0)}{D_n} \qquad (29)$$

For infinite time we obtain:

$$T(x,0)=\frac{eQb}{\lambda L}+\frac{Q}{\lambda L}\sum_{\substack{-\infty\\ n\neq 0}}^{+\infty}\frac{tanh\left(\sqrt{\omega_n^2+\frac{j\omega_n V}{a}}e\right)}{\sqrt{\omega_n^2+\frac{j\omega_n V}{a}}}\left(\frac{1-e^{-j\omega_n b}}{j\omega_n}\right)e^{j\omega_n x} \tag{30}$$

We can define the constriction resistance *Rc* trough the fluid in plug flow:

$$Rc=\frac{e}{\lambda}+\frac{1}{\lambda b}\sum_{\substack{-\infty\\ n\neq 0}}^{+\infty}\frac{tanh\left(\sqrt{\omega_n^2+\frac{j\omega_n V}{a}}e\right)}{\sqrt{\omega_n^2+\frac{j\omega_n V}{a}}}\left(\frac{1-e^{-j\omega_n b}}{j\omega_n}\right) \tag{31}$$

Fluid in Couette flow

We consider the same case but we only change the velocity profile, in order to simulate a Couette flow.

$$\frac{\partial^2 T^*}{\partial y^2}+\frac{\partial^2 T^*}{\partial x^2}+\frac{V(y)}{a}\frac{\partial T^*}{\partial x}=\frac{\partial T}{\partial t} \text{ with } V(y)=\frac{V(y=e)}{e}y \tag{32}$$

Initially, the whole system is assumed to be at uniform temperature *To*. A new variable is considered $T_i=T_i^*-To$.

Boundary conditions are given by:

- Periodicity of temperature and flux at *x=0* and *x=L*
- $\lambda\left.\frac{\partial T}{\partial y}\right|_{y=0}=\begin{cases}Q \text{ if } 0<x<b\\ 0 \text{ if } b<x<L\end{cases}$
- *T(e)=0*

For solving the equation, we discretise the fluid layer on *y*, and for each layer is assumed in plug flow (figure 5).

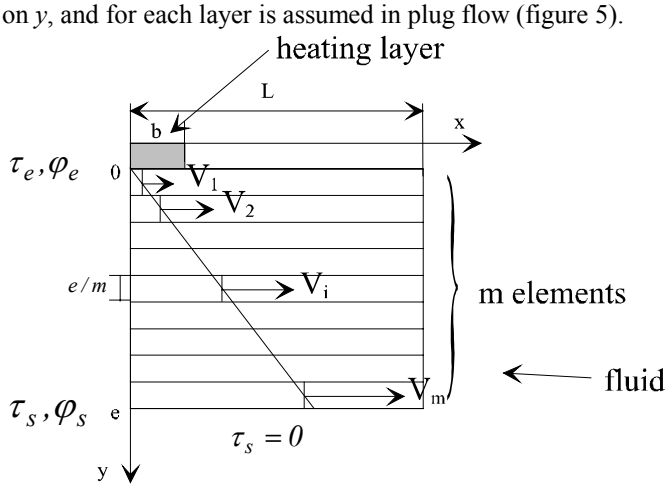

Figure 5: main geometrical parameters for a fluid in Couette flow

Each elementary layer can be described by the quadripole defined previously (equation 28). We use a typical property of quadripole to describe heat transfer trough multilayer system:

$$\begin{bmatrix}\tau(\omega_n,y=0)\\ \varphi(\omega_n,y=0)\end{bmatrix}=\begin{bmatrix}A_1 & B_1\\ C_1 & D_1\end{bmatrix}\begin{bmatrix}A_2 & B_2\\ C_2 & D_2\end{bmatrix}\cdots\cdots\begin{bmatrix}A_m & B_m\\ C_m & D_m\end{bmatrix}\begin{bmatrix}\tau(\omega_n,y=e)\\ \varphi(\omega_n,y=e)\end{bmatrix} \tag{33}$$

Where *m* is the number of layer.

Viscosity effects

We generally, must take account of the effect of viscosity on the heat transfer. In this case the heat equation becomes:

$$\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial x^2}+\frac{V(y)}{a}\frac{\partial T}{\partial x}+\frac{\nu}{\lambda}\left(\frac{\partial V(y)}{\partial y}\right)^2=\frac{1}{a}\frac{\partial T}{\partial t} \tag{34}$$

Temperature can be writen as the superposition of conductive transfer (T_{cond}) and viscosity effect (T_{visc}), it yields:

$$T(x,y,t)=T_{visc}(x,y,t)+T_{cond}(x,y,t) \tag{35}$$

We get the following system:

$$\frac{\partial^2 T_{cond}}{\partial y^2}+\frac{\partial^2 T_{cond}}{\partial x^2}+\frac{V(y)}{a}\frac{\partial T_{cond}}{\partial x}=\frac{1}{a}\frac{\partial T_{cond}}{\partial t} \tag{36}$$

$$\frac{\partial^2 T_{visc}(y,t)}{\partial y^2}+\frac{\nu}{\lambda}\left(\frac{\partial V(y)}{\partial y}\right)^2=\frac{1}{a}\frac{\partial T_{visc}(y,t)}{\partial t} \tag{37}$$

The equation 36 has been solved in previous section. We have just to solve equation 37. In Laplace space, equation 37 becomes:

$$\frac{\partial^2 \theta_{visc}(y,p)}{\partial y^2}+\frac{\nu}{\lambda}\left(\frac{V_{max}}{e}\right)^2\frac{1}{p}=\frac{p}{a}\theta_{visc}(y,p) \tag{38}$$

The solution is given by the quadripole formalism:

$$\begin{bmatrix}\theta_e^{visc}\\ \phi_e^{visc}\end{bmatrix}=\begin{bmatrix}A_{visc} & B_{visc}\\ C_{visc} & D_{visc}\end{bmatrix}\begin{bmatrix}\theta_s^{visc}\\ \phi_s^{visc}\end{bmatrix}+\begin{bmatrix}X_{visc}\\ Y_{visc}\end{bmatrix} \tag{39}$$

Where A_{visq}, B_{visq}, C_{visq}, *and* D_{visq}, are the typical terms of quadripole and X_{visc} and Y_{visc} are defined by:

$$X_{visc}=(1-A_{visc})\left(\frac{V_{max}}{e}\right)^2\frac{\nu}{p^2} \text{ et } Y_{visc}=-C_{visc}\left(\frac{V_{max}}{e}\right)^2\frac{\nu}{p^2} \tag{40}$$

Experimental results

Fluid used is a rodhorsil oil (ref 47V30000) λ=0.16 $Wm^{-1}K^{-1}$, ν=30 Pa.s and ρc_p=1.46 10^6 $Jm^{-3}K^{-1}$.

The sensitivity coefficients analysis shows possibility to estimate thermal conductivity, volumetric heat capacity and viscosity for Couette [15] flow, by using the thermogrammes obtained for different velocity values. We used a classical numerical estimation method, which minimize the norm between experimental values and exact solution.

For *V=0*, we obtain the volumetric heat capacity: ρc_p=1.38 10^6 $Jm^{-3}K^{-1}$ with a relative error of 10.2 %. In the following table, we show the influence of speed on estimation results. For $V<0.13\ ms^{-1}$, we have a good estimation of the

thermal conductivity. The speed influence is reverse for the estimation of viscosity.

Vmax (ms^{-1})	λ ($Wm^{-1}K^{-1}$)	Error λ (%)	ν (Pa s)	Error ν (%)
0	0.158	3		
0.08	0.161	3	10.5	60
0.13	0.163	4	25.2	25
0.2	0.15	10	31.9	10
0.25	0.165	12	29.8	6
0.31	0.138	15	31.1	4

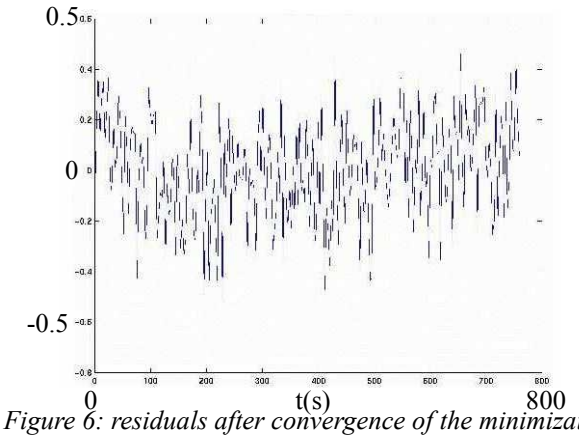

Figure 6: residuals after convergence of the minimization

The observation of residuals obtained ($Vmax$ = 0.13 ms^{-1}) on figure 6 is giving good agreement of the model and the convergence of the minimization

CONCLUSION

The new device presented in the first part of this paper is complementary to the classical hot wire method. Our method remains simple, but we can control the heat flux diffusion in the sample.

We show that the calculation of the constriction resistance calculation in the studied sample quickly gives an excellent first estimation of the thermal conductivity. We can estimate the thermal conductivity and the volumetric heat capacity with an ordinary lest square procedure, which minimizes the norm between experimental result and complete model. We also estimate the error on the parameters.

In the second part, we present a new method to estimate thermal conductivity, volumetric, heat capacity and viscosity of fluid in Couette flow. We develop an analytical model based on an extension of quadripole formalism to describe the heat transfer in fluid layer.

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