DESIGN OF NEW HOT-STRIP SENSORS TO MEASURE THERMAL CONDUCTIVITY OF IONIC LIQUID SYSTEMS

A.P.C. Ribeiro[1], M.J.V. Lourenço[1]*, F.J.V. Santos[1], J.M. Serra[2] and C.A. Nieto de Castro[1]

[1]Departamento de Química e Bioquímica and Centro de Ciências Moleculares e Materiais

[2]Departamento de Engenharia Geográfica, Geofísica e Energia e Centro de Sistemas de Energia Sustentáveis

Faculdade de Ciências da Universidade de Lisboa

Campo Grande, 1749-016 Lisboa, Portugal

*Corresponding author: mjlourenco@fc.ul.pt

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Introduction/Background: One of the most important thermal properties for developing new engineering fluids compatible with the sustainable chemistry is thermal conductivity. Ionic liquids are a class of fluids that have shown lots of possibilities for replacing existing fluids in chemical processing plants, and in other heat transfer applications. Current measurements of the thermal conductivity of ionic liquids have low to moderate uncertainties in thermal conductivity, a fact that recommends the development of high accuracy instrumentation, commensurate with what can be obtained for other fluids [1,2]. In this paper we report the design of new hot-strip sensors, operating in a transient regime, to determine the thermal conductivity of ionic liquids. The dynamic behaviour of the sensor was tested with air, water and $[C_2mim][EtOSO_3]$.

Experimental: The sensors were designed to accommodate the properties of the ionic liquids, and were obtained by Physical Vapour Deposition (PVD) deposition of platinum on a ceramic substrate, using a hot-strip configuration, inspired in our previous work [3,4,5].

The metallic platinum thin film deposited by PVD on Al_2O_3 and AlN substrates involves several operations. These are exemplified for alumina:

a) Drawing the geometric configuration chosen – the mask drawing.

b) Chemical etching of the alumina substrate.

c) Printing this drawing in serigraphic plate – photolithography; the thickness of the photoresist layer is less than 1 mm for the spin speed used. This layer is then exposed to UV light through a photomask.

d) Platinum metal deposition by PVD – This operation was performed in the PVD Evaporator (SESUL-FCUL). On the alumina substrates (RUBALIT, RUBALIT 708S and RUBALIT 708 HP by CeramTec, DE), a titanium layer of 100 Å and platinum strips (Pt disc 99,99% by Umicore) were deposited.

e) The deposited layer thickness is continuously measured by an oscillating quartz crystal monitor unit. The e-gun used in this work is an EV M-5 gun made by AP&T, with a maximum power of 4 kW. The evaporation rate was kept slow in order to achieve good deposition homogeneity in the film and started when the vacuum in the chamber was smaller than 1.3x10-3 Pa.

f) Lift-off – It was done with developers AZ 400 K and AZ 351B and AZ100 remover from Microchemicals/Clariant.

g) Leads soldering –the soldering of the electrical cables to the platinum ports of the sensors was done with silver basedCircuitWorks® Conductive Epoxy glue CW2400 from CHEMTRONICS.

h) Heat treatment of the metal thin-film - After the deposition of the titanium and platinum films, heat treatments were performed in air

i) Alumina deposition of insulating layer – single crystal aluminium oxide was used (99,98% of Al_2O_3), deposited by the same technique

The sensor obtained is has a width around 60 μm, determined using an optical microscope and a thickness of 0.5 μm. The two strip have lengths of 5 and 3 cm.

An attempt was made to design the sensors (length, width and thickness) to match as close as possible the transient hot-wire behaviour, although the study of the dynamic characteristics of the sensor using sample results in air, allows the complete identification of the heat transfer occurring in the ceramic/platinum film, ceramic alumina coating/media, that use different time scales.

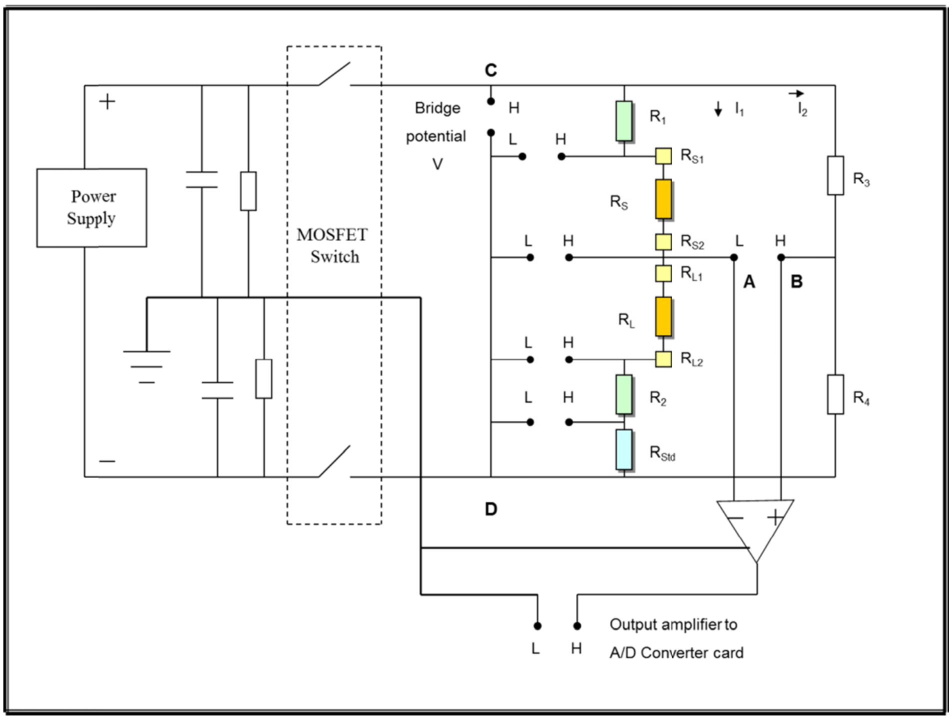

Figure 1. Simplified schematic of the bridge circuit [6].

The measuring system used has been previously described [6], and it is composed by an automatic Wheatstone bridge, capable of measuring the temperature rise in the hot strip as a function of time. Two sensors of different lengths are placed in different arms of the automatic Wheatstone bridge, to compensate for the distortion of the transient temperature fields in the edges of the platinum thin-film. Figure 1 shows a schematic of the measuring bridge. The resistance values of R_3 and R_4 were changed to accommodate the values of the current strip resistance values. R_S and R_L represent the short and long strip.

Results and discussion: For an infinitely long and infinitely thin strip, and assuming that the "end effects", are non-existing, the main solution for the temperature rise in the hot-strip ΔT can be approximated by Eq. (1):

$$\tau = \frac{\sqrt{k_f t}}{l} \qquad k_f = \frac{\lambda}{\rho C_\mathrm{P}}$$

$$\Delta T = T(t) - T_0 = \frac{q}{4\lambda\sqrt{\pi}} f(\tau) \tag{1}$$

$$f(\tau) = \tau \,\mathrm{erf}\left(\frac{1}{\tau}\right) - \frac{\tau^2}{\sqrt{4\pi}}\left[1 - \exp\left(-\frac{1}{\tau^2}\right)\right] + \frac{1}{\sqrt{4\pi}} E_i\left(\frac{1}{\tau^2}\right)$$

where k_f is the thermal diffusivity of the media, q is the heat dissipated per unit length of the strip, l is the length of the strip (the difference between the lengths of the long and short strips), τ is a dimensionless time, and λ the thermal conductivity of the media where heat transfer takes place. The mathematical functions erf (y) and Ei(z) are, respectively the error function and the exponential integral, obtainable from rational approximations and easily programmed. We found that the function $f(\tau)$ is a linear function of ln (τ), for a $0 < \tau < 1000$, given by Eq. (2), with a regression coefficient $r^2 = 1$ ($\varepsilon < 10^6$):

$$f(\tau) = 0.5642 \ln(\tau) + 0.6835 \tag{2}$$

Figure 2 shows the dynamic behaviour of the sensor, registering the temperature rise in the hot strip, as a function of of ln (τ), for a run with a time limit of 6 s. It is very clear that the linear portion of the ideal model prediction only appears for ln (τ) > 5.7, which means between 3 and 6 seconds. It is clear that the warming feels first the metal strip ($\lambda_{\mathrm{Pt}} \sim 71$ $\mathrm{Wm^{-1}K^{-1}}$), then the ceramic substrate (support and coat) ($\lambda_{\mathrm{Al2O3}} \sim 24$ $\mathrm{Wm^{-1}K^{-1}}$) and finally the media (air in this case. The application of equations 2 and 3 to the experimental result give $\lambda_{\mathrm{air}} \sim 26.7$ $\mathrm{mWm^{-1}K^{-1}}$, a value that can be compared with the reference value at 22.03 ºC and 0.1 MPa of 25.9 $\mathrm{mWm^{-1}K^{-1}}$. We hope to improve this preliminary data in a near future.

These results will be complemented by data on water and [C_2mim][$EtOSO_3$] between room temperature and 120ºC.

Conclusions: The present results show that the transient hot-strip theory can be applied to the simulation of the heat transfer behaviour of the new hot-strip sensors, both in air and an ionic liquid. Improvement of the data analysis will make possible in the near future to obtain the thermal conductivity of ionic liquids with an estimated global uncertainty of 2%.

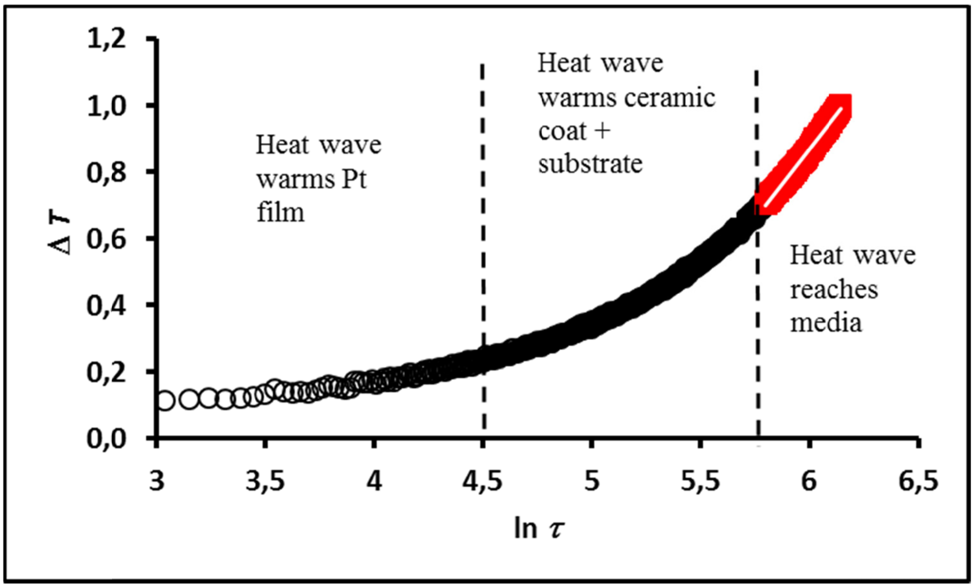

Figure 2. Dynamic sensor response for a run in air.

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