TECHNICAL NOTE

Measuring the thermal conducitivity of uranin

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A convenient experimental method for measuring the thermal conductivity of uranin (fluorecein sodium, $C_{20}H_{10}O_5Na_2$) is described. Two similar blocks of uranin, produced from a strong uranin/water solution, were exposed to one-dimensional steady-state conduction. It was found that, for a mean bulk temperature ranging from ambient up to 55 °C, the uranin has a constant thermal conductivity of 0.43 W/mK. Above these temperatures, the material begins to soften and the termal conductivity is seen to decrease

Key words: *thermal conductivity, aerosols, experimentation + steam turbines*

Diffusive deposition of steam fog droplets on low pressure steam turbine stator blades has been studied for a number of years in the Wet Steam Laboratory at the University of Liverpool[1–4] using experimental simulation techniques in which solid uranin (fluorecein sodium) particles have been injected into a flow of air over a test cascade of turbine stator blades. Uranin has been a successful material on which to base the studies because submicron particles can be produced easily in a Collison atomiser and any deposition which subsequently occurs can be detected and evaluated by fluorimetric means.

The more recent theoretical study of the behaviour of steam fog droplets within the boundary layer of the steam flow over a turbine stator blade by Al-Azzawi and Ryley[5] accommodated the coupled effects of all the forces present, eddy diffusivity, brownian motion and thermophoresis, were all allowed for together with local evaporation, and their combined effects observed as the droplets passed through the boundary layer. To assess the validity of their theoretical study, Al-Azzawi applied the analysis to a situation which could be readily repeated in their laboratory, the effect of thermophoresis on submicron uranin particles in air flows.

Successful application of the analysis requires a value for the thermal conductivity of the uranin which does not appear to be available in the published literature or from conventional sources[6–9]. This paper aims, therefore, to provide a value for the thermal conductivity of uranin, which may be of more general interest than simply to research workers in aerosol physics, and to present a simple and convenient experimental method for determining thermal conductivity of such materials.

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Received 24 August 1983 and accepted for publication on 21 December 1983

Experimental apparatus and procedure

The thermal conductivity of a material is essentially a function of its substance, temperature, and internal geometric structure, but is independent of the external geometric shape (ie sphere, cube, etc). Therefore, by arranging that the test specimen has the same internal structure as the uranin particle of interest, the thermal conductivity becomes a function of temperature only. The uranin particles used in the aerosol simulation experiments are produced by atomising a water/uranin solution. After the water evaporates in the air stream, a small uranin particle remains; the internal structure of the particle, particularly the void fraction, will be a function of its drying rate. The uranin test pieces which were used to measure the thermal conductivity were produced from a strong water/uranin solution which was allowed to dry at room temperature, ie at the same temperature as the aerosol particle, to produce a similar internal structure.

The experimental apparatus used is shown in section in Fig 1. With this arrangement, two uranin samples could be investigated simultaneously. Each sample was located on the opposite surface of the slab of good insulating material. Mounted on each side of the insulating material was a copper coated laminated sheet 140 mm square. Some of the copper film was peeled off the outer surface of each sheet to leave a central area, 60 mm × 60 mm, as a heating element. Five thermocouples were mounted on the heating surface to measure the surface temperature of the uranin sample. The two heating elements were connected in series by heavy copper wires to enable a relatively large current to be drawn from the power supply. A wooden frame with internal dimensions, 60 mm × 60 mm was placed over each heating element. The uranin test pieces were then individually cast into these frames to produce solid blocks, one being 6.4 mm thick and the other 7.15 mm, designated block 1 and block 2 respectively. Five thermocouples

 0142-727X/84/010057-03$03.00

were then attached to the outer surface of each of the test pieces.

This arrangement permitted two uranin blocks of different thickness to be exposed to one-dimensional steady-state conduction. The electrical current through the copper heating elements was measured together with the potential differences across each to yield the power supplied to each block. Air was continuously blown over the outer surfaces of the test blocks to assist the heat transfer and to increase the measured temperature difference between the inner and outer surfaces.

Results and discussion

Fouriers equation for one-dimensional steady-state conduction reduces to $q = KA\,\Delta T/\Delta X$ where K is the thermal conductivity, A the cross-sectional area normal to heat flux and $\Delta T/\Delta X$ is the temperature gradient through test block. It is assumed that the electrical energy supplied to the heating elements is conducted through the uranin test blocks as heat flux, q. Since A and ΔX are geometric constants the thermal conductivity will be a function of $q/\Delta T$. A linear relationship indicates a constant value of K while a curvilinear relationship indicates that K is temperature dependent. The variation of the heat flux through the two uranin blocks as a function of the temperature difference measured across them is shown in Fig 2. The derived values for the thermal conductivity as a function of the mean bulk temperature in the blocks $\bar{T}$ is shown in Fig 3. These values were calculated using the slope measured between consecutive points in Fig 2.

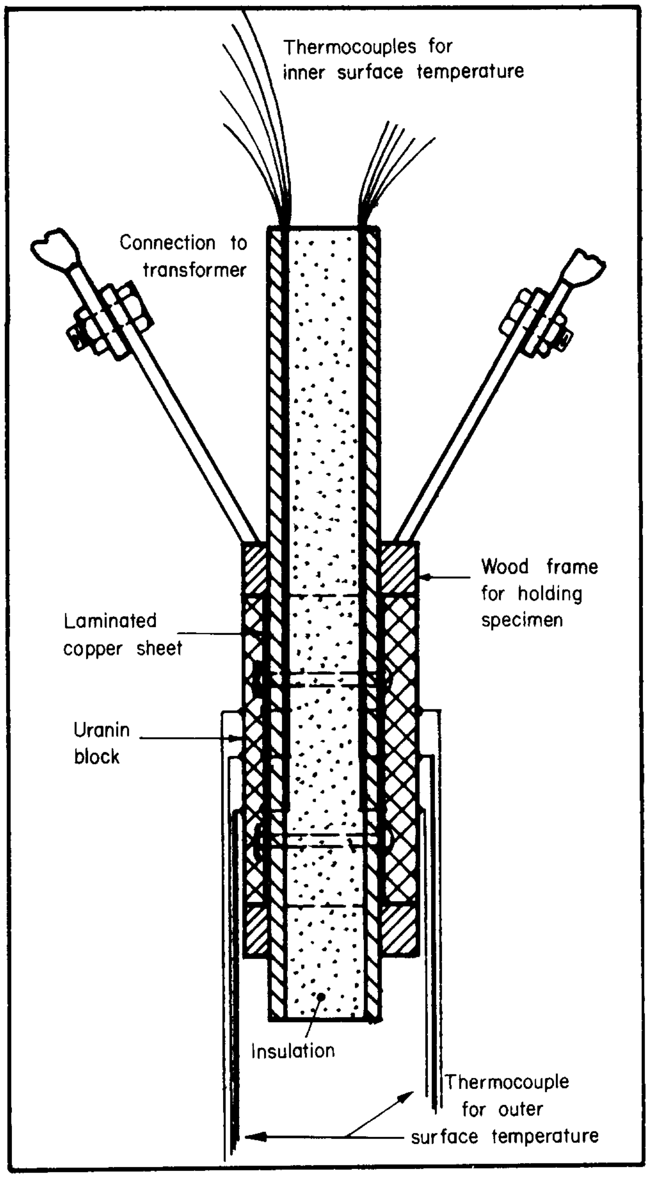

Fig 1 Cross section of the experimental apparatus

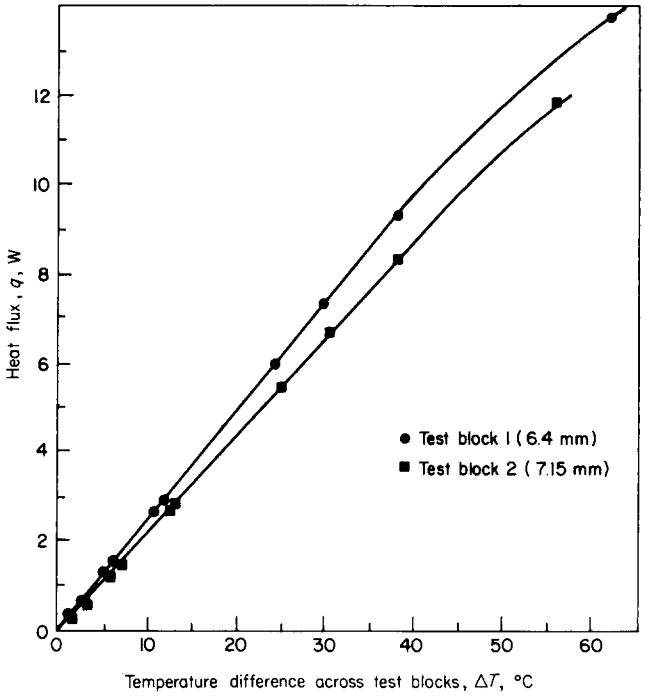

Fig 2 Variation of heat flux through test blocks with temperature difference

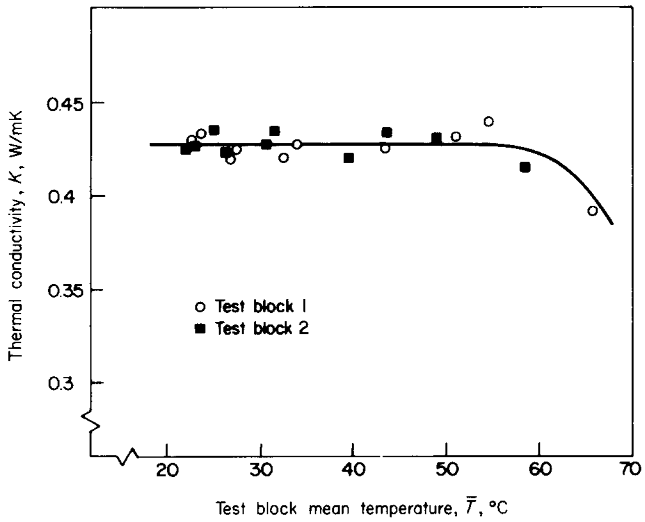

Fig 3 Thermal conductivity of solid Uranin

Figs 2 and 3 show clearly that the thermal conductivity of the uranin has a constant value up to an average test block temperature of about 55 °C after which it is seen to decrease. At the higher average temperatures, the heated surface temperature was as much as 90 °C and the test blocks were beginning to soften. The apparent temperature dependency of the thermal conductivity at higher temperature is, therefore, more likely to be the result of a change in the structure of the material. For the temperature range in which the uranin can be sensibly used as a solid material, the thermal conductivity has a constant value of about 0.43 W/mK.

The errors involved in the experiment were estimated to be of the order of 2%. These were mainly due to voltage fluctuations from the thermocouples and a slight variation in the thickness of the test blocks after solidification. The scatter in the results of Fig 3 reflect this error. A least squares regression analysis in the linear portion of Fig 2 would give a single value for the corresponding section of Fig 3. The individual data points and their scatter were retained and plotted in Fig 3, however, as a demonstration of the experimental consistency.

Conclusions

To complement a long term research programme involving experimental and theoretical aerosol techniques, it has been necessary to find the thermal conductivity of uranin (fluorecein sodium). Two solid uranin test blocks were manufactured by allowing a strong water/uranin solution to dry out and solidify. The blocks were exposed to one-dimensional steady-state conduction by heating one surface using electrically heated copper elements. The experimental method was found to be very satisfactory and produced a constant value for the thermal conductivity of uranin of 0.43 W/mK.

Acknowledgements

The authors wish to acknowledge the assistance and suggestions received from Drs D. J. Ryley and H. Barrow.

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CONFERENCE REPORT

12–14 September 1983, University of Karlsruhe, FRG

Fourth Symposium on Turbulent Shear Flows

Evidence of the increasing interest in shear flows was found at this, the fourth in a series of biennial symposia, in the large number of papers (nearly 100) spread over 18 sessions, 12 of which were held in parallel pairs. In addition there were two Open Forum sessions at which workers were able to talk briefly about current research. The papers were selected from 190 extended abstracts, and of those selected, it is intended that about 30 will be published formally by Springer-Verlag, following the practice with the previous symposia. Doubtless a number of the other papers will appear in journals or other publications. The symposium was well attended, attracting some 250 participants.

In a short report it is clearly impossible to give adequate coverage of all the topics discussed at the symposium. Thus the report is written from the point of view of one on the edge of the subject and more interested in its engineering implications than concerned with fundamental aspects of turbulent shear flows. The papers mentioned below are grouped somewhat arbitrarily, and in some cases cutting across the grouping of the symposium sessions.

Internal and external boundary layer flows

In this traditional area which has received attention for many decades, there were some interesting ideas and developments. Two papers on compressible flow were presented. Vandrome *et al*[2] presented a new calculation method for internal boundary layers including shock waves, and Muck and Smits[5] studied the boundary layer/shock interaction at a 16° corner, presenting details of the turbulence quantities.

Perry *et al*[1] studied the flow over a regular rough surface comparing shear stress values with those for a smooth surface. Andreopoulos *et al*[3] studied the details of flow close to the wall in a large wind tunnel using a hot wire temperature wake sensor.