Defence Science Journal, Vol. 54, No. 4, October 2004, pp. 515-524

PC-based Data Acquisition System for Thermal Conductivity Measurement of Snow

A.K. Singh, Vrushali Deo, and G.C. Pant
*Institute of Armament Technology, Pune–*411 025

ABSTRACT

A PC-based data acquisition/measurement system has been presented for the thermal conductivity of snow, using thermal probe. The thermal probe is a transient method of thermal conductivity measurement and has advantages in terms of short-run time, smaller temperature rise, and *in situ* measurement applications. The developed data acquisition system does intelligent management of different sensors for thermal conductivity, and is based on RS-232 serial communication with RS-485 data conversion, providing additional advantage of long-distance measurement in field conditions. The hardware and software features of the system are described and its performance for different materials along with test results, is presented.

Keywords: PC-based data acquisition system, thermal conductivity, snowcover, measurement system, thermal probe, transient method, RS-485/422 protocol, ADAM-4520, data acquisition system, avalanche forecasting

1. INTRODUCTION

The temperature distribution within a snowcover, plays an important role in the formation of avalanches. This temperature distribution changes continuously due to energy exchange between the snowcover and the atmosphere, which is responsible for metamorphic changes in snow, and hence, strength properties, leading to the formation of avalanches. Thus, exact knowledge of thermal conductivity of snow is an important parameter for modelling the temperature distribution as it plays a key role in avalanche forecasting.

Various expressions are available in the literature for predicting the effective values of thermal conductivity of porous and dispersed systems. These expressions only provide a general idea and do not give the exact values. However, these play a major role in assessing the magnitude of temperature within the materials. In particular, when working with materials like snow, reliable data of thermal conductivity is obtainable through experimentation as thermal conductivity of snow depends not only on index parameters but also on micro parameters[1]. In the recent past, thermal conductivity studies performed, aimed to quantify the effects of various parameters on thermal conductivity, which further warrants that the measurement method needs to be very accurate and precise. The need for a highly precise technique for measuring the thermal conductivity of snow has also been emphasised by Strum[2], *et al.* The scatter in the reported values of thermal conductivity has been attributed to measurement errors besides other factors. Also, reported values on thermal conductivity lack detailed information about snow, thus restricting its applicability.

Revised 10 March 2004

Literature survey reveals that there are many more methods for measuring the thermal conductivity of snow, which can be grouped into two categories–steady-state methods and transient methods. The steady-state methods are simple in theory, but their practical application involves an elaborate experimental setup, including thermal guard system[3] to eliminate the lateral heat flow. The effect of moisture migration is also a problem due to prolonged steady-state temperature gradients imposed on a test sample. Also, a large test sample is required for the measurement. Moreover, these methods do not permit *in situ* measurement. All these disadvantages of steady-state methods can be overcome using transient methods. As quoted by Strum[2], *et al.* more than 27 studies on the thermal conductivity of snow have been reported since 1886. Mostly, the measurements reported have been done manually or semi-automatically, by recording the temperature of sensor and then analysing the temperature data to obtain the value of thermal conductivity. In these studies[2,4-7], needle probe method, supposed to be an accurate method of thermal conductivity measurement for materials like snow was used. In the present study, transient needle probe (thermal probe) method has been chosen because of the aforesaid reasons. Ewen and Thomas[8] have done an in-depth analysis of the thermal probe method. Details about the probe theory, its applications and limitations, are available in the literature[9-11].

This study aims to automate the process of measuring the thermal conductivity of snow. With this, the temperature rise during measurement will be reduced and the measurements can be performed accurately, near to proximity of melting point of snow, and also at multiple points, simultaneously and quickly, and the database, along with snow properties, can be developed automatically. Data acquisition system developed allows intelligent management of different sensors. The treatment of data is in real-time, and transfer of data is carried out through a bi-directional serial port using RS-232C protocol, and then RS-485/422 protocol for long-distance communication.

The data acquisition system has been developed using ADAM-4018 module[12] (trade name of Advantech, USA), with in-built signal conditioning for thermocouple input and analog-to-digital converter. ADAM- 4520 isolated RS-232 to RS-422/485 converter module is used for interfacing ADAM-4018 with a PC. ADAM-4520 and ADAM-4018 are kept in IP66 cabinet, which can withstand temperature from –20 °C to 40 °C. The application software is written in C/C++ with the front-end in VC++. The developed data acquisition and the analysis software are user-friendly, with multichannel measurement of thermal conductivity, online graphical display, and data storage. The thermal conductivity instrumentation is compact, rugged, and suitable for both laboratory and field applications under low-temperature conditions.

2. PHILOSOPHY OF THERMAL CONDUCTIVITY MEASUREMENT

The thermal conductivity measurement method, viz., thermal probe method (Fig. 1), is based on the simplified mathematical solution of a line heat source in a homogeneous medium. The thermal probe is made of metal cylinder with integral constant power heater and temperature sensor. The temperature of the cylinder rises as heat dissipates. The method for analysing available temperature data has been derived from the theory of heat conduction of a line heat source embedded in an infinite homogeneous medium. The theoretical solution of the problem shows that the temperature response of the probe, when plotted against the natural logarithm of time, becomes linear after a relatively long time. After being burried in the sample, the probe is allowed to come to the thermal equilibrium with the medium, and the power is switched on. The temperature of the needle probe rises and heat is dissipated into the surrounding medium. The rate of dissipation of heat is a function of the thermal conductivity of the surrounding material, besides other factors. The effective thermal conductivity (K) is evaluated using a suitable identification procedure and recording the variation of probe temperature with time:

$$T_2 - T_1 = \frac{q}{4\pi K} \ln(t_2/t_1)$$

where T_2 and T_1 are the temperatures at times t_2 and t_1, and q is the power supplied to the probe heater and calculated by measuring the current in probe heater wire of known resistance.

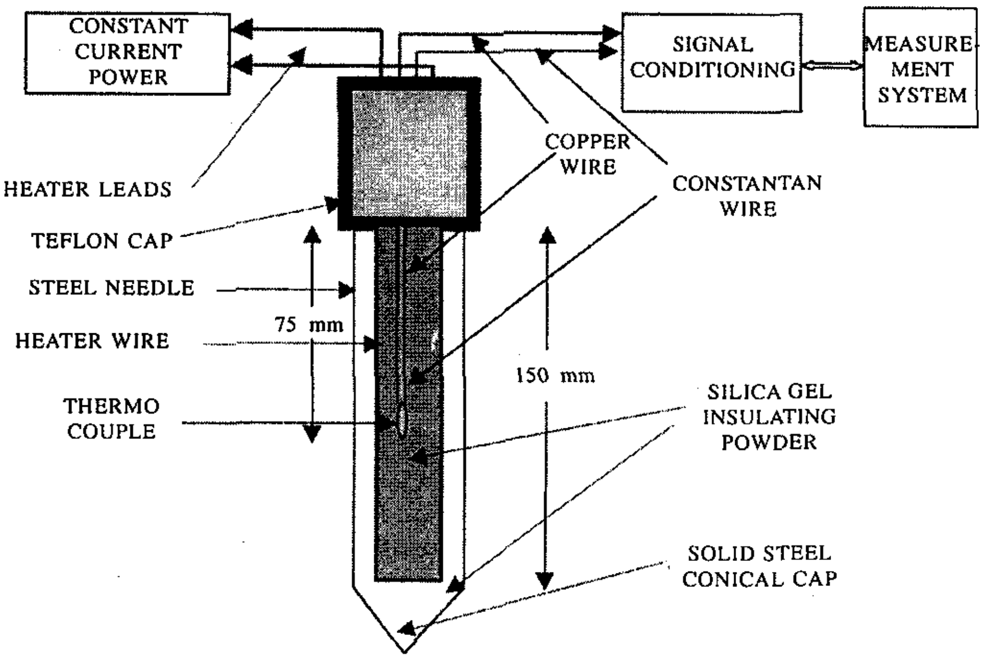

Figure 1. Basic thermal conductivity measurement setup

3. DATA ACQUISITION SYSTEM

The block diagram of an automated thermal conductivity measurement system is shown in Fig. 2.

In this figure, ADAM-4018 is a thermocouple-type temperature sensor data acquisition add-on module, having in-built signal conditioning for thermocouple sensors. ADAM-4018 consists of an

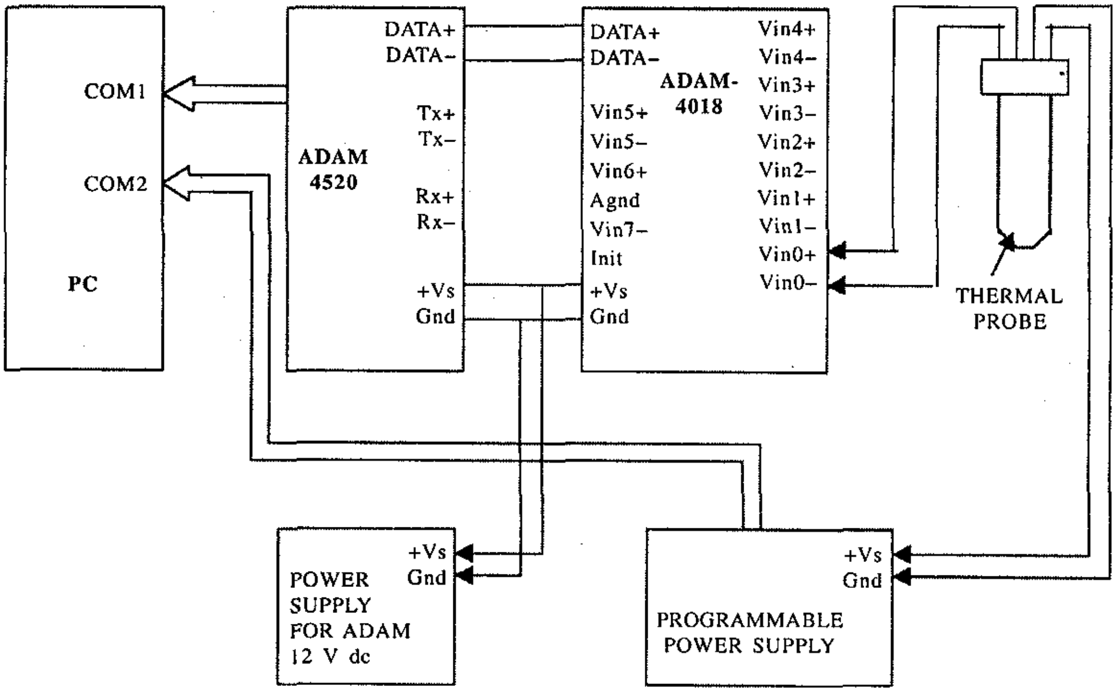

Figure 2. Schematic block diagram and connection diagram of automated thermal conductivity measurement setup

8-channel analog multiplexer (ADG-508) for eight analog signals. The buffer provides isolation and impedance matching. The programmable gain amplifier (PGA) can vary its gain from 1 to 128. The PGA automatically adjusts the signal to a range –2.5 V to +2.5 V. This is the optimal input voltage range. The analog-to-digital converter used has 16-bit resolution and analog-to-digital conversion is supervised by microcontroller that holds the calibration software. Two types of calibrations take place automatically on start up or reset, ie, auto-zero calibration and auto-span calibration. Normal calibration is used to adjust signals according to the user-defined calibration parameters. A two-terminal temperature transducer, IC AD-590 produces an output current and absolute temperature. During calibration process, user can change the ambient temperature sensed by this IC. The digital 10 Hz low-pass filter provides steady-state output. The opto-isolator ISO PC 400 prevents the ground loops and limits the chance of damage from power surges. Cold-junction compensation (CJC) calibration is in-built. The microcontroller is the main controlling unit in this circuit, which performs the following basic functions:

(a) *Communication software & command set*: Configuration for address , input range, baud rate , data format , type of thermocouple used, are stored in EEPROM (Atmel 93C56) at the time of program execution.

(b) *Calibration*: CJC calibration, auto-zero calibration, and auto-span calibration are done before program execution. A 0.0 mV signal is applied to channel 0 of multiplexer for auto-zero calibration, while 22.0 mV signal is applied for auto-span calibration. The microcontroller automatically adjusts these values in actual measurement.

(c) *Data transformation*: After start signal is received from the software, data is transformed into the right data format as configured earlier. Output data is passed on to RS-485 format with the low power, half-duplex RS-485.

3.1 RS-422/485 & PC Communication

The RS-485 is an EIA standard specially used for long-distance communication, up to 1220 m. If the host computer has RS-485 interface, the ADAM-4520 is not required. The RS-485 standard supports half-duplex communication using only two wires (data+ and data–). The RS-422 standard can further increase the distance, but at the cost of using four wires (–Tx, –Rx, +Tx, +Rx). The ADAM-4520 consists of a communication controller, which converts RS-422/485 into RS-232 (Tx, Rx, RTS, Gnd). The direction control logic automatically detects the direction of data flow, so user does not require to specify the direction of the data flow. The opto-coupler isolation protects the host computer from static charges and wiring faults. The baud rate can be set with micro-switch sw1 (1200, 2400, 4800, 9600,19.2 kbps baud rate). Also, the digital format setting, ie, eight engineering units, two complement hexadecimal formats or percentage of full-scale range (FSR), can be adjusted with micro-switch sw 2.

3.2 Software Functions

The functions of application software are described in a flow chart (Fig. 3), and are as follows:

Step 1. Initialise the ADAM cards: (i) configure the ADAM modules for COM-1, 9600 baud rate, 8-bit data, 1-bit stop, no parity format data, and (ii) enable/disable the ADAM-4018's multiplexer channels.

Step 2. Test for the proper working of hardware, ie, power supply failure and wrong connections.

Step 3. Get the number of probes (maximum four in the present application), samples, sampling period, probe parameters, snow details, data file name, etc. from the user.

Step 4. Store these entered values in the data file for reference, with system date and time. Link the VC++ program to C++ program through text file as shown in the Fig. 4.

Step 5. Initialise EGA/VGA driver and graphics mode.

Step 6. Auto-scaling of X-axis (time axis) is automatically done with the user-entered

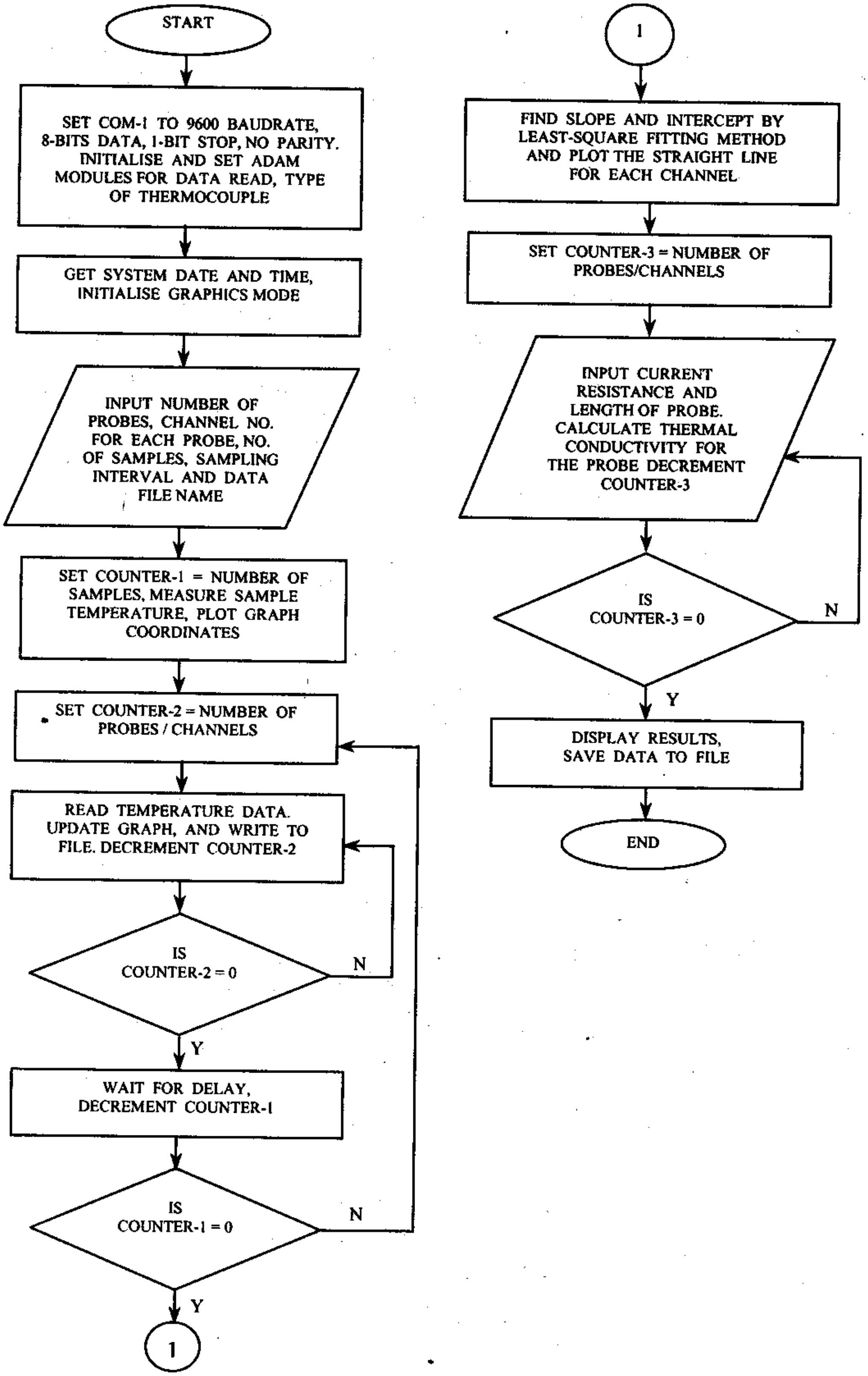

Figure 3. Software configuration of thermal conductivity measurement system

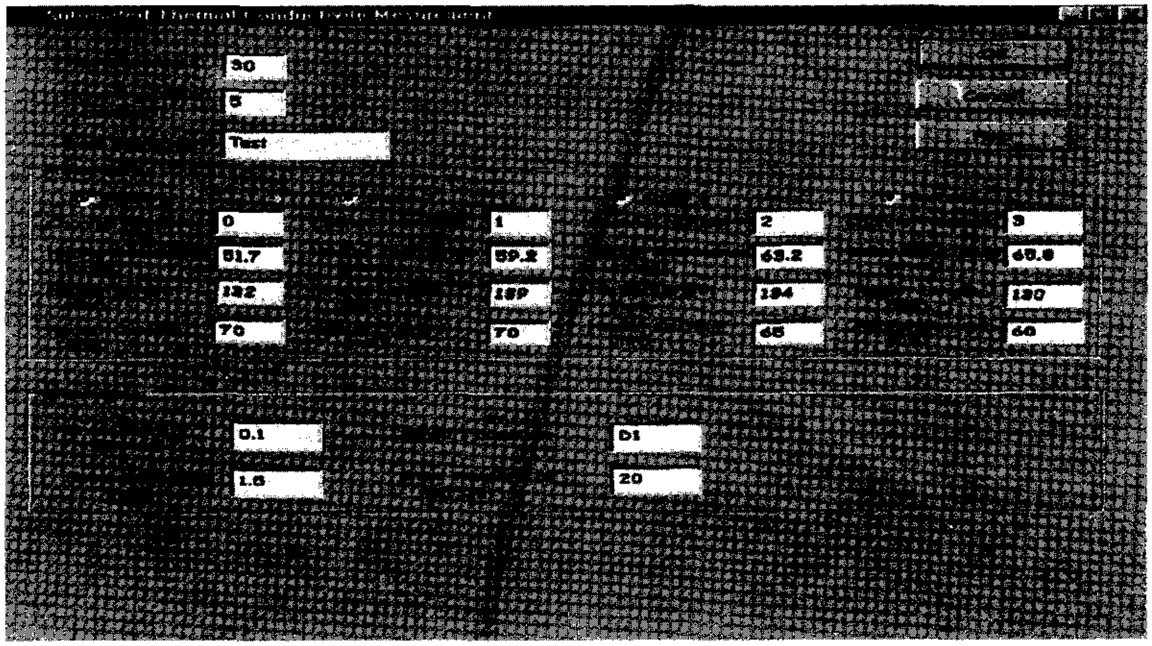

Figure 4. Screen output of front-end for automated thermal conductivity measurement system

sampling time and sampling rate (both determining the duration of test). Auto-scaling of Y-axis is done on the basis of first reading of snow temperature, keeping in view the expected rise in temperature during the test run.

Step 7. Switch on the programmable power supply, as soon as the measurement of temperature starts.

Step 8. Measure the sample temperature with time and convert the data into decimal form.

Step 9. Store these details in data file as well as plot the graph according to the observed temperature on real-time.

Step 10. Plot the slope of graph using least-square method, when the measurement is complete.

Step 11. Calculate the values of thermal conductivity using probe parameters and slope of the graph.

Step 12. Print the values of thermal conductivity and also store these along with snow information, with system date, in the data file.

Step 13. If the user wants to do next test, accept the parameters for the next test, otherwise, stop the execution.

3.3 PROGRAMMABLE POWER SUPPLY

The HAMEG HM-8142, a two-channel programmable power supply is used with RS-232 interface (Com2 port) with PC. The HM-8142 is a linear power supply with resolution of 10 mV and 1 mA for voltage and current. It can be operated either in the constant-current mode or constant-voltage mode. The main parts of HM-8142 are power unit, analog part for each channel, controller, and display unit. The power unit provides external modulation and voltage supply for other cards. Analog parts A and B for each channel consist of a digital-to-analog converter and an analog circuitry for constant voltage and constant current output. The HM-8142 controller unit uses microcontroller 80C31 and RS-232 communication system.

4. RESULTS & DISCUSSION

The thermal probe experiments have been conducted to measure the thermal conductivity of glycerol (99.5 % purity). The glycerol has been selected due to its high viscosity, which allows heat transfer only by conduction. Also, contact resistance of glycerol is minimum for the probe-to-liquid contact, which makes it most suitable for the purpose. The amount of input power to the probe, for the test sample, must be carefully selected to ensure that conduction is the only mode of heat transfer. The value of current is selected such that the overall temperature rise is within 4 °C-5 °C. A number of thermal conductivity measurements for glycerol have been taken for the sampling period of 1 s to 5 s and the number of samples from 10 to 50. A test run output of PC screen has been shown in the Figs 5 and 6 for glycerol for 10

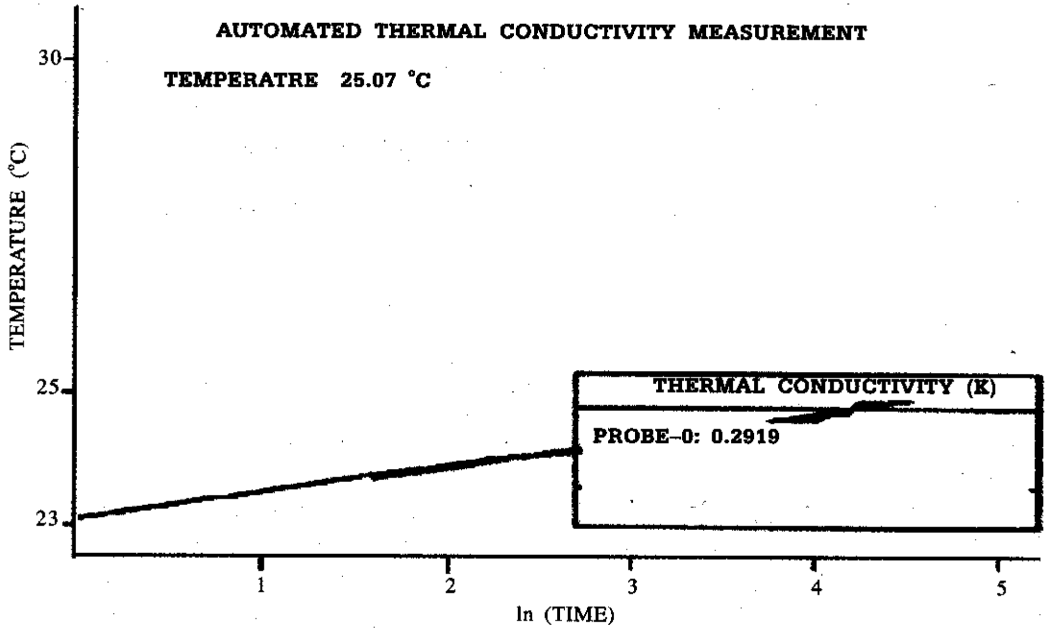

Figure 5. Output graph for glycerol for 10 samples, 2 s sampling period and 70 mA current

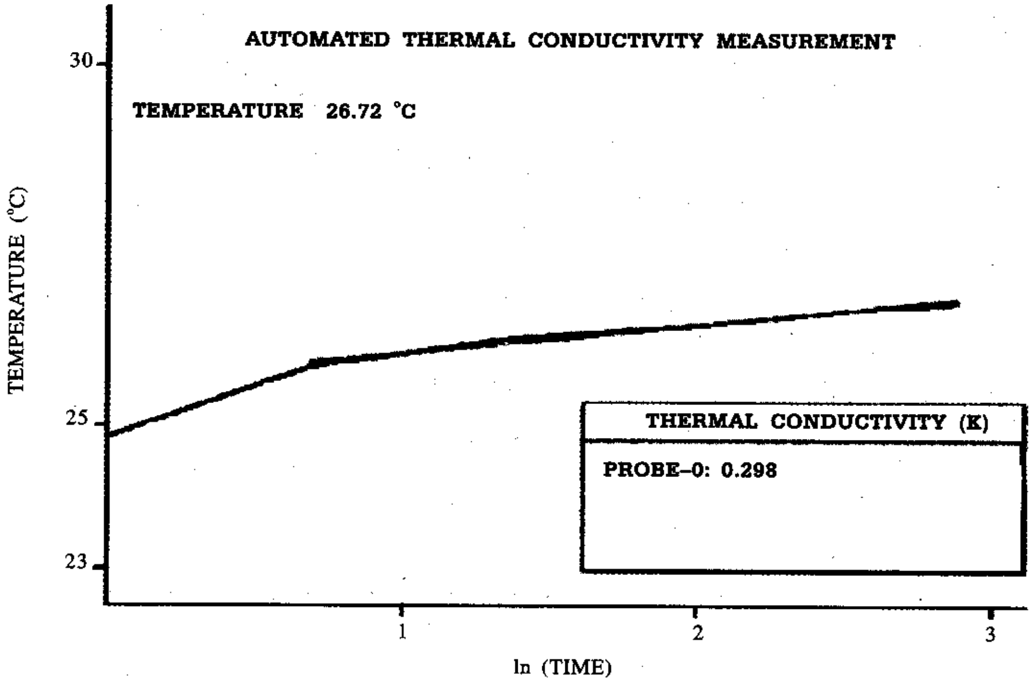

Figure 6. Output graph for glycerol for 30 samples, 2 s sampling period and 70 mA current

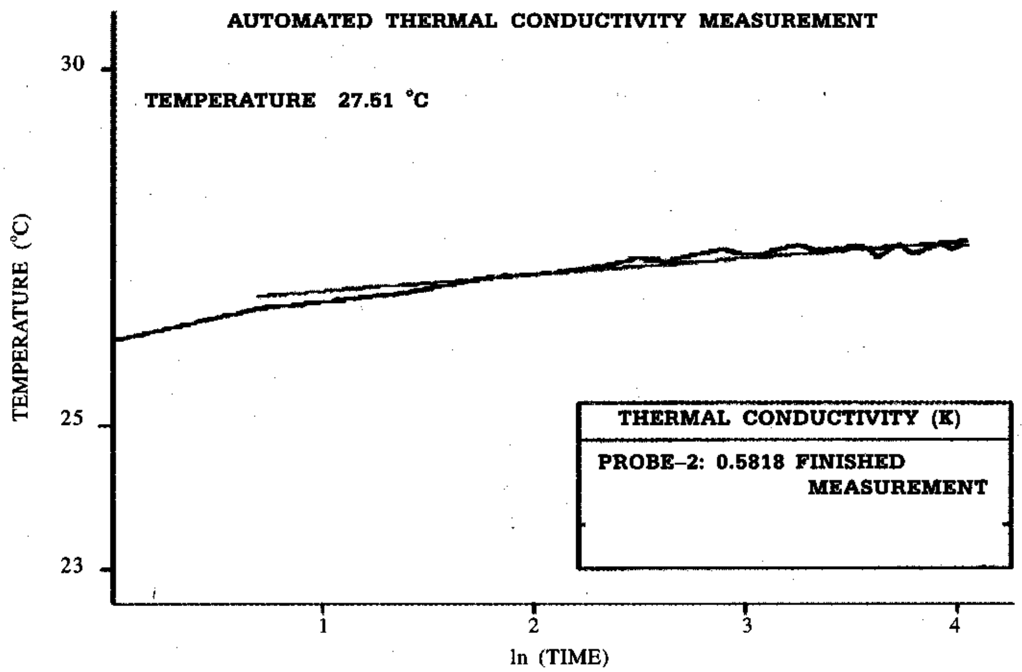

Figure 7. Output graph for distilled water for 25 samples, 2 s sampling period and 50 mA current

samples and 30 samples, respectively. Figures 7 and 8 are the screen output for distilled water and sawdust. In Fig. 9, output graph is shown for simultaneous measurement of four samples, ie, glycerol, kerosene, benzene, and sawdust. The standard values of thermal conductivity for glycerol, distilled water, kerosene, sawdust, and benzene are 0.289 $Wm^{-1}K^{-1}$, 0.602 $Wm^{-1}K^{-1}$, 0.149 $Wm^{-1}K^{-1}$, 0.059 $Wm^{-1}K^{-1}$, and 0.158 $Wm^{-1}K^{-1}$, respectively. A large number of measurements have been performed on these materials.

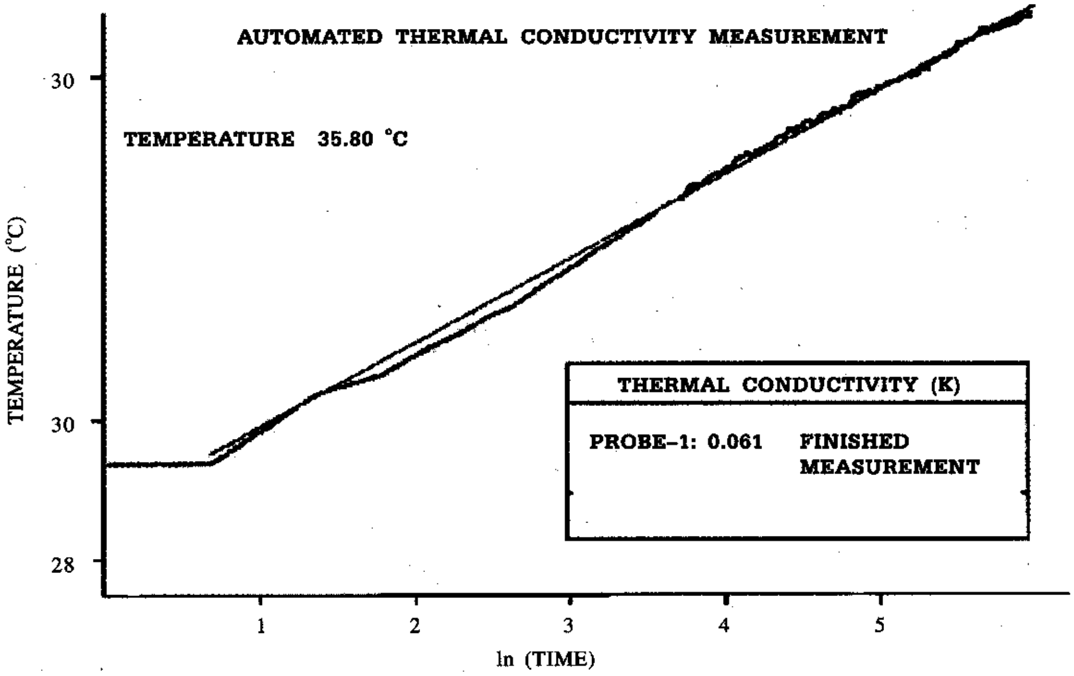

Figure 8. Output graph for sawdust for 200 samples, 2 s sampling period and 60 mA current

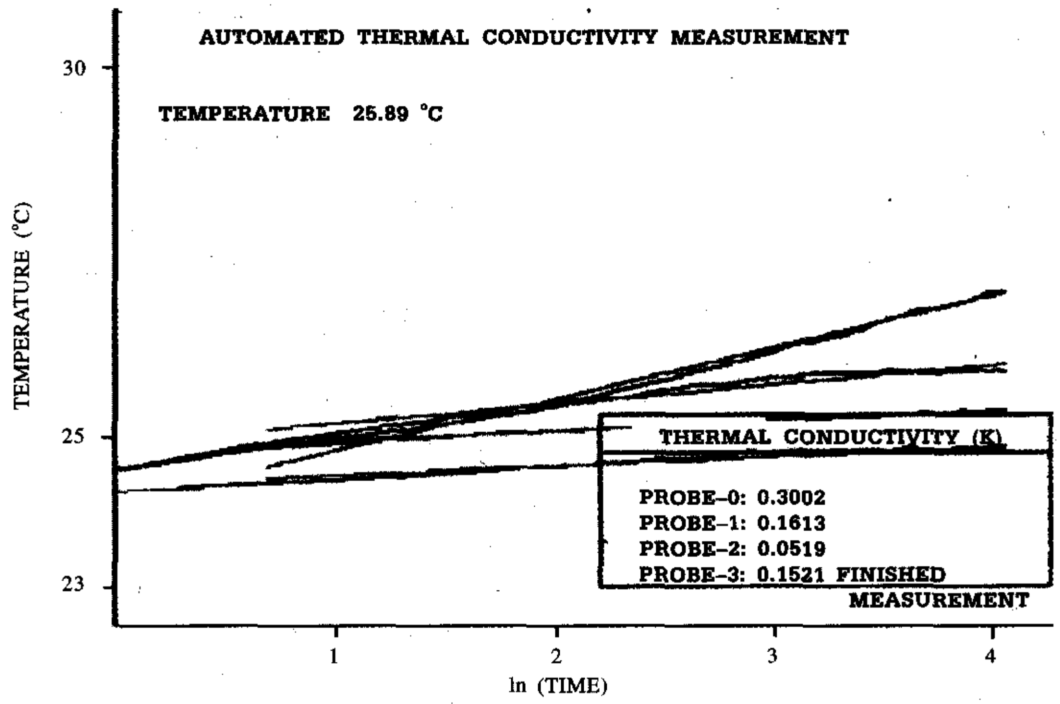

Figure 9. Output graph for four-channel measurement for 30 samples and 2 s sampling period (probe-0: glycerol, 70 mA; probe-1: benzene, 60 mA; probe-2: sawdust, 50 mA; probe-3: kerosene, 60 mA).

The maximum percentage error from the standard value, along with standard deviation (shown within brackets), for glycerol, distilled water, kerosene, and sawdust, are 5.11(0.012), 3.34(0.013), 6.10(0.006), and 6.94(0.002), respectively. These errors are the maximum observed errors. However in most cases, errors are below or around 3 per cent. The errors can also be partially attributed to material composition and impurities. On each test run for the same file, the data file appends the test results and the corresponding snow parameters. After the test, the data file is stored in the same directory as the application program. The developed instrumentation is being used at the Snow & Avalanche Study Establishment (SASE), Manali, for the measurement of thermal conductivity of snow under laboratory and field conditions.

ACKNOWLEDGEMENTS

Thanks are due to the Director, SASE for the financial assistance, and to Sarvashri P.S. Negi and R.K. Aggrawal, Scientists from the SASE, Manali, for providing exact requirements, testing of the developed instrumentation for snow measurement in the laboratory and in the field, and their critical evaluation. Thanks are also due to the Director, Institute of Armament Technology (IAT), Pune, for granting permission to publish this work.

REFERENCES

1. Adams, E.E. & Sato, A. Model for effective thermal conductivity of a dry snowcover composed of uniform ice spheres. *Annals of Glaciology*, 1993, **18**, 300-04.
2. Strum, M.; Holmgren, J. ; Koing, M. & Morris, K. The thermal conductivity of seasonal snow. *Journal of Glaciology*, 1997, **43** (143), 26-41.
3. Pitman, D. & Zuckerman, B. Effect of thermal conductivity of snow at –88 °C, –27 °C and –5 °C. *J. Appl. Phys.*, 1967, **38**(6), 2698-699.
4. Jaafar, H. & Picot, J.J. Thermal conductivity of snow by transient state probe method. *Water Resour. Res.*, 1970, **6**(1), 333-35.

5. Lange, M.A. Measurements of thermal parameters in antarctic snow and firn. *Annals of Glaciology*, 1985, **6**, 100-04.
6. Strum, M. & Johnson, J.B. Thermal conductivity measurements in depth hoar. *J. Geophys. Res.*, 1992, **97**(B2), 2129-139.
7. Singh, A.K. An investigation of the thermal conductivity of snow. *Journal of Glaciology*, 1999, **45**(150), 346-51.
8. Ewen, J. & Thomas, H.R. The thermal probe: A new method and its use on an unsaturated sand. *Geotechnique*, 1987, **37**(1), 91-105.
9. Carslaw, H.S. & Jaeger, J.C. Conduction of heat in solids. Claredon Press, Oxford, 1959.
10. Singh, A.K. & Chaudhary, D.R. Prediction of effective thermal conductivity of moist porous materials. *Journal of Physics. D: Applied Physics*, 1990, **23**, 698-02.
11. Singh, A.K. A PC-based transient method for thermal conductivity measurement. *Def. Sci. J.*, 2000, **50**(4), 343-50.
12. ADAM 4000 series data acquisition modules, Users manual, Advantech, USA, 1997.

Contributors

Dr A.K. Singh received his PhD from the University of Rajasthan, Jaipur, in 1992. Presently, he is working in the Dept of Instrumentation, Guided Missiles Faculty at the Institute of Armament Technology (IAT), Girinagar, Pune. His areas of research include: Piezoelectric sensors, PC-based instrumentation, thermal sensors, laser instrumentation, and smart materials. He has published more than 30 papers in various national/international journals.

Prof G.C. Pant obtained his BE(Aeronautical Engg) from the PEC, Chandigarh and ME (Space Engg & Rocketry) from the BIT, Ranchi. He joined DRDO in 1976. Presently, he is the Chairman of Guided Missiles Faculty at the IAT, Pune. He is a specialist in missile propulsion and some of his contributions are–setting up test rigs and research facilities, such as propellant processing, RAM rocket, solid rocket, liquid rocket test facilities, etc. He has done many research projects on propulsion systems related to IGMDP.