$\partial^2 U/\partial Y^2$ and $\partial^2 T/\partial Y^2$ in equations (5) and (6) respectively but as ΔY and V are small these discretization errors will not have a marked effect on the numerical calculations. This was in fact verified numerically in that the solutions were not too sensitive to the choice of ΔY. The terms $(U\Delta X/2)(\partial^2 U/\partial X^2)$ and $(U\Delta X/2)(\partial^2 T/\partial X^2)$ effectively add, artificially, diffusion in the X direction. Thus if $Pr = 1$ we may consider the coefficients of these second derivatives in X being inversely proportional to a "Reynolds number", R say, i.e.

$$R = \frac{2}{U\Delta X}. \tag{7}$$

With the values of U and ΔX used in the calculations it is found that near the maximum value of U then R is $O(1)$. Obviously near the plate and at the outer edge of the boundary layer U is very small and the value of R is therefore very large. Since it is at the maximum value of U where the disturbance from the leading edge is travelling fastest, which in turn determines the position up to which the unsteady solution is valid, it is important that the detail of the solution should be correct here. Because of this artificial adding of a large amount of diffusion in the X direction in this critical region it is not therefore surprising that the results of this method do not agree with the analytical results.

It should be remembered that a possible mathematical solution to this problem is that for $\tau < \tau_c^*$, some critical value of τ, the unsteady solution holds whereas for $\tau > \tau_c^*$ the steady solution is valid and the solution is discontinuous at $\tau = \tau_c^*$. If this is the only solution to equations (1)–(3) it is not surprising that the results obtained using the methods described in [5–7] may fail to converge. Whereas using the method described in [1–3], and used here, which artificially adds diffusion in the X direction will obviously converge to an answer which in the limit as $\Delta X \to 0$ or $X_{max} \to \infty$ and $\Delta Y \to 0$ will approach the true solution. As observed from Figs. 1 and 2 taking these limits for a fixed ΔY shows a tendency for the transition from the unsteady to the steady solution to be more rapid and maybe the above mathematical solution is the one to which the results are tending.

One may add in a variable mesh in order to reduce the computing time and yet keep good detail near $X = 0$ and $Y = 0$ as was used by Callahan and Marner [3] but the values of $\Delta X/X_{max}$ and $\Delta Y/Y_{max}$ used here were smaller than the finest meshes used in [3]. Although they quote results which agreed to within 7% when the space mesh was halved one can see from the results presented here that this is not a sufficient test to the accuracy of the method.

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Int. J. Heat Mass Transfer. Vol. 21, pp. 69–73. Pergamon Press 1978. Printed in Great Britain

USE OF THE MICROTRANSIENT THERMAL DIFFUSIVITY MEASURING TECHNIQUE ON LIQUIDS: IMPLICATIONS ON FLUIDS OF THE "WEAK INFRARED ABSORBING" CLASS

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(*Received* 25 *May* 1976 *and in revised form* 13 *October* 1976)

NOMENCLATURE

- C, temperature [°C];
- m, distance [m];
- C_p, specific heat [J/kg°C];
- α, thermal diffusivity [m^2/s];
- k, thermal conductivity [W/m°C];
- ρ, density [kg/m^3].

INTRODUCTION

THE PURPOSE of this short communication is to report the results of new work performed with the "microtransient diffusivity measuring system" since that previously reported [1, 2], and to summarize experimental modifications effected to increase measurement accuracy. Specifically, the new work addressed the class of so called "weak IR absorbing" fluids [3, 4]. For this class of fluids, including carbon tetrachloride and toluene, the results support the conclusion that experimental techniques for measuring thermal conductivity may have a systematic error in results reported, if care is not taken to discriminate against the detection of energy transfer by radiation when energy transfer by conduction is the desired process being measured.

The data generated by this technique were for measurement distances significantly smaller than those used by any other existing heat-transfer measurement techniques, and implied for the "small" distances used a larger radiation contribution potential than previously determined for "weak IR absorbing" fluids.

NEW MEASUREMENTS, AND RESULTS FOR LIQUIDS OF THE WEAKLY IR ABSORBING CLASS

By way of summary, Appendix A presents a schematic of the measuring technique developed and already reported, as well as modifications made to the measuring system to increase the precision of the measurement from that originally developed. In the apparatus, as it is currently used, a cylindrical line source (~200 μm long) acts as a short duration transient energy input (~200 μs) within a transparent test fluid. The source, created from a biological laser coupled to an inverted metallurgical microscope, induces shock, radiation, and thermal transients in the test fluid. The

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detector, a "butt welded" microthermocouple (25 μm dia), is located parallel to the line source (less than 100 μm separation distance used between source and detector), and detects the ensuing shock and thermal transient. The latter is detected significantly delayed in time after the initial energy deposition. Relative sensitivity to radiation is minimized (in comparison to plate type measuring devices) by geometry and by the transient nature of the measurement. The actual quantity measured is thermal diffusivity, but by careful use of fluids for which relatively precise thermophysical data (ρ and C_p) are available, results can be used to arrive at conclusions about the thermal conductivity parameter of energy transport.

Table 1 is a summary of measurement results, including data previously reported, expanded to permit comparison with new data. Multiple data references are shown where more current thermophysical property recommendations were available subsequent to those used in [1] and [2].

thermophysical properties. Figure 1 summarizes thermal conductivity data by these investigators on four of the fluids which have been used in this investigation. To facilitate comparison, diffusivity data has been converted to equivalent conductivity values via property data of Table 1, and corrections have been made to common temperatures. When available, the TPRC series on Thermophysical Properties of Matter [7] recommended values are also included in the comparisons. The general agreement for the two "strong" IR absorbing fluids, water and *n*-propanol, is shown. However, for the two "weak" infrared absorbing fluids, the deviation from the TPRC recommended value at small distances is obvious. Furthermore, data from the subject method taken at less than 0.1 mm indicates a possibly lower "zero" distance extrapolated value than those determined by all other investigators. The question of small distance extrapolation on thermal conductivity data appears to warrant further detailed investigation.

Table 1. Experimental results for transient thermal diffusivity measuring technique

Liquid	Source* purity	Measurement temperature (°C)	Measured† density $\left(\frac{kg \times 10^{-3}}{m^3}\right)$	Heat capacity $\left(\frac{J \times 10^{-3}}{kg\ °C}\right)$	Thermal conductivity $\left(\frac{W}{m\ °C}\right)$	Calculated thermal diffusivity $\left(\frac{m^2 \times 10^8}{s}\right)$	Measured‡ thermal diffusivity $\left(\frac{m^2 \times 10^8}{s}\right)$	Measured§ thermal diffusivity
Water	a	23.0	0.9975	4.186	0.5972 [7]	14.30	14.52 ± 0.36	
		19.7	0.9982	4.186	0.597	14.25		14.61 ± 0.4
Glycol	1b	21.0	1.115	2.399 [13]	0.257 [7]	9.60	9.60	
Ethanol	c	20.0	0.793	2.403 [14]	0.164 [4]	8.61	8.37 ± 0.06	
				2.386 [7]	0.168 [7]	8.88		
1-Propanol	1b	22.0	0.803	2.353 [14]	0.152 [4]	8.04	7.90 ± 0.07	
		22.1						7.97 ± 0.2
1-Pentanol	1b	20.6	0.815	2.319 [14]	0.137 [6]	7.26	7.55 ± 0.06	
Toluene	3e	20.4	0.867	1.700 [15]	0.131 [4]	8.86	8.13 ± 0.33	
				1.701 [7]	0.136 [7]	9.22		
		20.6	0.864	1.701	0.131 [4]	8.91		7.88 ± 0.27
Carbon Tet.	1b	19.4	1.58	0.862 [15]	0.973 [4]	7.14	6.43 ± 0.21	
				0.854 [7]	0.105 [7]	7.78		
		19.9	1.59	0.854 [7]	0.971 [4]	7.15		6.33 ± 0.2
n-Hexadecane	2d	20.7	0.773	2.210 [16]	0.152 [17]	8.91	7.70 ± 0.07	
Heavy water		21.0	1.1054	4.207 [18]	0.578 [18]	12.4	11.78 ± 0.12	

* *Source*: 1. Fisher Scientific Co.; 2. Eastman Kodak Organic Chemicals; 3. Baker Chemical Co. *Purity*: (a) Doubly distilled; (b) Certified reagent (99% min); (c) absolute; (d) Practical (95% min); (e) Analyzed reagent (98.6% min).

†Westphal balance.

‡Experimental data previously published [1, 2].

§New data being reported in this publication.

Note—Deviations shown are "average deviations of the mean".

As reported in [2], agreement between measured results and those obtained from the literature is good (within 5%) when the technique is applied to fluids not in the weak IR absorbing class. However, for fluids in the latter class, such as carbon tetrachloride and toluene, the subject measurement technique yielded significantly different thermal diffusivity results from those expected using literature data. The difference is attributed to the thermal conductivity parameter, in the absence of radiative energy transport. Measurements with the original, as well as altered, detection configuration [Appendix, Figs. 3(a and b)], support the conclusion that for measurements on "weak infrared absorbing" fluids, the value of thermal conductivity determined for very small measurement distances is significantly lower (more than 10% lower at small distances) than that expected from existing thermal conductivity surveys [5–7]. Reference [7] apparently recognizes this fact in its discussion section, but its published recommended values do not yet have weightings reflecting the discussion.

DISCUSSION OF RESULTS

The work reported above supports the conclusion that the specific work of Poltz and Jugel [4] and of Schoedel [8, 9], in which the researchers have analyzed their data to discriminate against energy transport by radiation, should receive special recognition and weighting in future compilations of

In conclusion, it is noted that although the reported transient thermal diffusivity measurement data, converted to thermal conductivity values, may have larger inherent uncertainties than occur in directly measured thermal conductivity data derived from numerous existing techniques (such as those reported by Tye [10], and [11]), the subject technique obtains data in smaller measurement distances (less than 0.1 mm) that used in all the standard reported techniques. For these short distances this technique sheds light in the nature of energy transport in the class of weak infrared absorbing fluids, indicating that further work on the zero distance extrapolated value of thermal conductivity is warranted.

FUTURE PLANS

In addition to further investigations on the nature of heat transfer at small measuring distances, it is planned to use the small measuring volume (such as 0.01 cc or less) capability of the subject method to attempt to measure the influence on the local heat-transfer process of "solvated" electrons [12] in "electron stabilizing fluids" (such as organic resonant ring compounds) many of which, interestingly enough, are also carcinogenic in nature. This may permit using the subject device as a micro-calorimeter (its original development purpose) for strong local ionizing sources, such as a polonium alpha source.

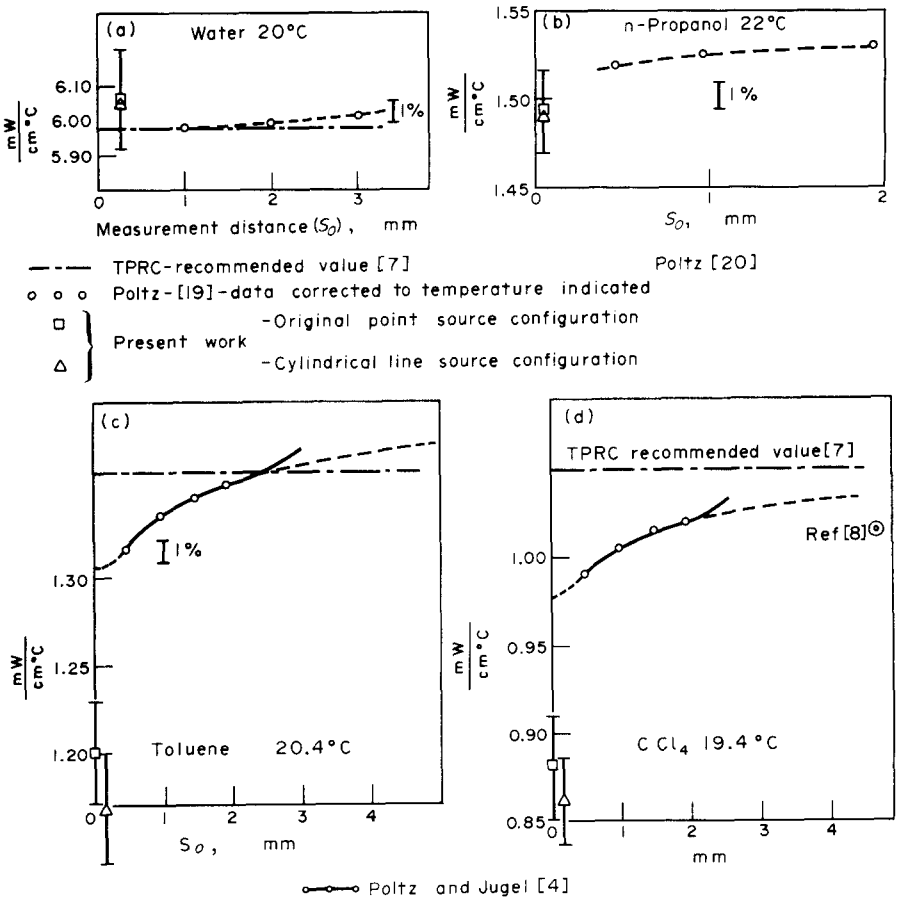

FIG. 1.

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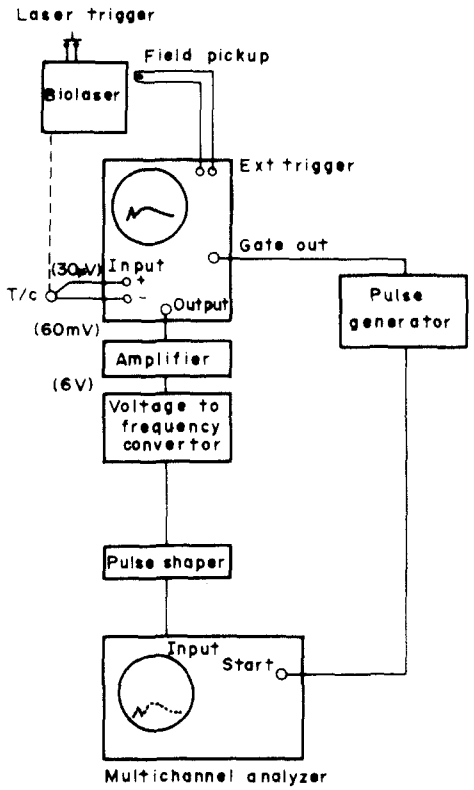

FIG. A1. Schematic of thermal transient measurement system data acquisition configuration.

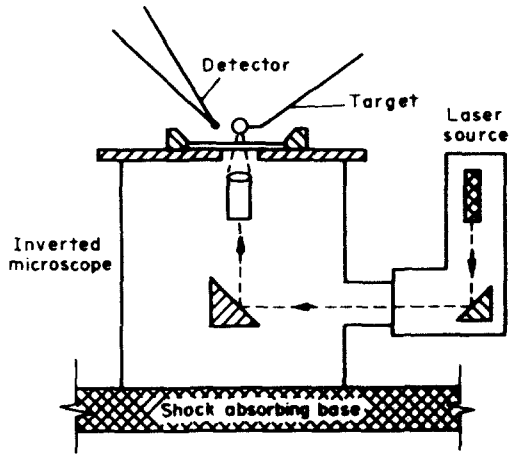

FIG. A2. Schematic of the optical portion of the thermal transient measurement system.

APPENDIX

Figure A1 is a schematic of the thermal transient measurement system, and Fig. A2 is a sketch of the optical portion. Energy from a small 0.3 J ruby laser is focused via the photographic channel of an inverted metallurgical microscope on a target wire which acts as a local source in the test

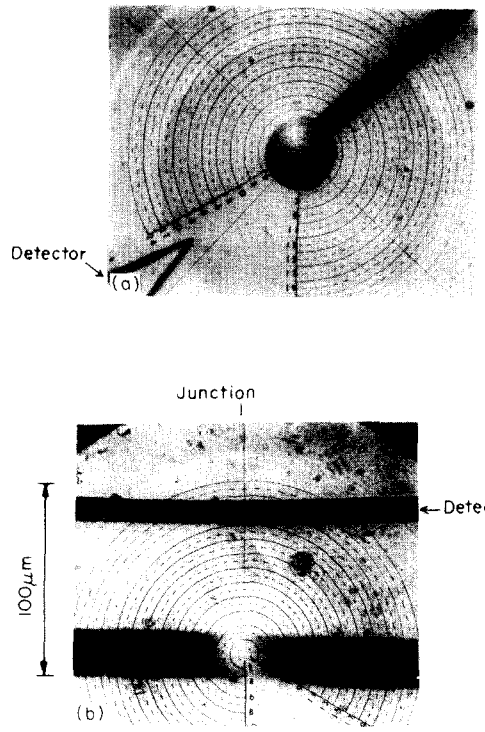

FIG. A3. (a) Microphotograph of heat source and thermocouple positioned for a measurement, in original configuration [1, 2] (reticle lines are 3.83μm apart). (b) New measurement configuration showing parallel measurement arrangement for cylindrical heat flow situation.

fluid. Whereas in the previously documented system a point source was created (Fig. A3a), now a line source configuration is used (Fig. A3b). Therefore, the heat flow has been converted from spherical flow to essentially cylindrical flow.

This change was chiefly done to minimize the "lead effects" of the detection thermocouple by placing them parallel to the transient isotherms, but was also done to create a new configuration to independently check the "anomalous" measurements on the "weak IR absorbing" fluids.

Figure A4 shows the data used for the subject discussion with computer generated curves indicating degree of fit to the data. It may be noted that the raw oscilloscope trace shows a first and second transient peak. The first is due to "shock" energy transfer, and the second is the thermal transient used in the subject measuring technique. Although it appears that the subject device could therefore be used to investigate the ratio of photo to phono conduction, the time constant of the microthermocouple detector being comparable to the period in which shock energy is transmitted, makes use of the early information difficult, although not impossible. In any case, both geometry and time are used to separate the two peaks for resolution between "photo" and "phono" energy transmission.

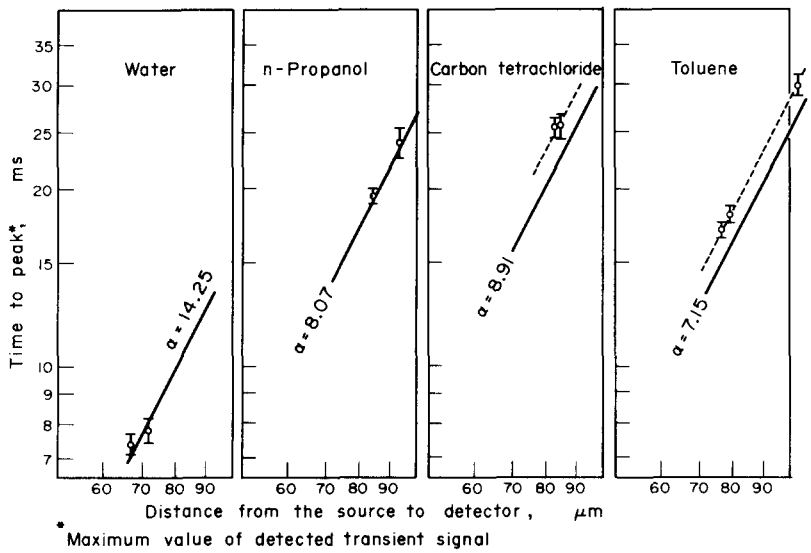

FIG. A4. Experimental data used for conclusions in subject communication, and comparison with an analytic model.

Int. J. Heat Mass Transfer. Vol. 21, pp. 73–75. Pergamon Press 1978. Printed in Great Britain

NUCLEATE BOILING OF *n*-PENTANE, *n*-HEXANE AND SEVERAL MIXTURES OF THE TWO FROM VARIOUS TUBE ARRAYS

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(*Received* 24 *September* 1976 *and in revised form* 14 *June* 1977)

INTRODUCTION

THE CHARACTERISTICS of pool boiling outside single horizontal tubes have been intensely studied in the past 25 years. Considerable knowledge has been accumulated about pressure effects, critical heat flux, and nucleation, for various surface geometrics. However, two of the most important unknowns for the designers of boiling heat-transfer equipment, the effect of multicomponent mixtures and multitube bundle geometry on boiling performance have received only a small amount of attention [1–19].

Katz and co-workers [2, 3] boiled refrigerants from a vertical row of four horizontal heaters and found that the upper tubes in the bundle had a higher heat-transfer coefficient at the same heat flux. They also injected vapor into the system under the bottom of the lowest tube to determine what effect the vapor flow had on the heat-transfer rate. Injection of vapor produced the same results as those observed on the top heater in their four tube array.

Recent work [5–7] indicates that additional circulation and turbulence caused by rising bubbles can increase the bundle heat-transfer coefficient above that for a single tube. This increase would indicate that instead of a vapor penalty, a multitude enhancement correction must be applied for correlation.

Rhodes and Bridges [9] studied the effect of mixture composition on boiling heat transfer and found that the addition of either dilute sodim carbonate or oleic acid in water promoted boiling. Cichelli and Bonilla [10] found that binary mixtures boiled with a lower heat-transfer coefficient than that for either component when boiled alone. The lower fluxes found by Cichelli and Bonilla have been confirmed by numerous studies [11–14].

Van Stralen and Sluyter [15] found that the maximum heat flux for mixtures compared to the heat flux for the less volatile pure component increased steadily with increasing pressure. It was also noted that the maximum value of the critical heat flux occurred at a certain low concentration of the most volatile component.

In attempting to explain the problem of critical heat flux, van Stralen and co-workers [17–19] presented a theoretical approach for the mechanisms of the critical heat flux. When comparing binary data to this theory, a generalized correlation does not result.

EXPERIMENTAL EQUIPMENT

The experimental equipment used in this investigation can be conveniently classified into five subsystems: heat-transfer elements, boiling and condensing vessel, pressure measurement and control equipment, power supply system, and temperature measurement equipment.

The equipment was similar to equipment described previously [5, 6, 20, 21] therefore, the equipment description will not be covered in detail here.

The four heat-transfer elements used in this investigation had an outside diameter of 0.0266 m (1.048 in) and a length of 0.126 m (4.96 in). All heat-transfer elements were plated with gold in order to maintain the surface chemistry of the heat-transfer surface relatively constant during the tests.

The boiling and condensing system is shown in Fig. 1. The boiling and condensing sections were constructed of commercial 0.1524-m (6-in) Pyrex pipe tees and the vapor line connecting the two was a 0.1524-m (6-in) Pyrex pipe elbow. The system pressure was controlled to the nearest 338 N/m^2

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