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HEAT TRANSFER—A REVIEW OF CURRENT LITERATURE

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INTRODUCTION

THIS REVIEW is concerned with research in the field of heat transfer, the results of which have been published during 1965. The total number of papers in this field continues to be so large that only a selection can be included. A more detailed listing is contained in the "Heat Transfer Bibliographies" published periodically in this Journal.

The 1965 Heat Transfer and Fluid Mechanics Institute was held in June at the University of California, Los Angeles. It was dedicated to Dean L. M. K. Boelter on the occasion of his retirement. Approximately two-thirds of the 22 papers presented at the meeting were connected with heat transfer in the field of plasma technology, ablation, and radiation. Proceedings of the conference are available at Stanford University Press. The 8th National Heat Transfer Conference was held at Los Angeles, California, in August 1965. Two invited lectures were given by J. W. Westwater and E. Schmidt. The second lecturer received, at the same meeting, the Max Jakob Memorial Award. One-hundred and five papers, a panel discussion on loss of coolant accidents in nuclear reactors, and an open forum completed the program of this conference. The papers are, or will be, published in the *Journal of Heat Transfer* or in the journals of the American Institute of Chemical Engineers. Several issues in the *Chemical Engineering Progress Series* published in 1965 were concerned with heat transfer. Number 57 contains the papers sponsored by the A.I.Ch.E. and presented at the 6th National Heat Transfer Conference, and Number 59, those presented at the 7th National Heat Transfer Conference. Number 58 is devoted to selected topics in transport phenomena.

Several books appeared on the market which deal with fields related to heat transfer. They are listed at the end of this paper.

The following areas of heat transfer found special attention in 1965 as judged from the number of publications. The instability limits in free convection as well as the motions after onset of flows were studied in a number of papers. A numerical analysis, for instance, described these motions in detail up to a Rayleigh number of 10^7. Heat transfer on rotating surfaces, with and without forced flow, and with or without mass transfer, found attention in an increasing number of papers. Analyses were performed on energy exchange by thermal radiation in absorbing and scattering media as well as in enclosures with surfaces, the reflectances of which were prescribed to vary directionally and also in the degree of polarization. Techniques and apparatuses for the measurements of temperature and heat flux have been reported. The large number of parameters influencing heat transfer in packed and fluidized beds is obviously the reason for the continuously large number of experimental studies and of attempts at correlations. A similar situation exists in the field of boiling and dropwise condensation where bubble or droplet formation, the influence of surface characteristics, and transition between various regimes were investigated. The large number of publications in the field of thermodynamic properties made a strict selection necessary. Only properties with special relevance to heat transfer are included in this review.

Transient state and moving boundaries with phase exchange found special attention in the field of conduction. The thermal entrance region in channel flow, both for hydrodynamically developed flow and for hydrodynamically developing flow was investigated. In the field of boundary layers, a closer look is now being taken into the details of chemical reaction, dissociation, and ionization processes—their dynamics and influence on heat transfer. Experimental studies on ionized boundary layers confirmed previously published information. Thermal diffusion may influence heat transfer by up to 20 per cent. Several investigations studied the characteristics of thermal radiation from heated gases in the plasma range. Thermal accommodation coefficients and heat transfer in channels were studied in the low density field.

To facilitate the use of this Review, a listing of the subject headings is made below in the order in which they appear in the text. The letter which appears adjacent to each subject heading is also attached to the references that are cited in that category.

Conduction, A.
Channel flow, B.
Boundary-layer flow, C.
Flow with separated regions, D.
Transfer mechanisms, E.
Natural convection, F.
Convection with rotating surfaces, G.
Combined heat and mass transfer, H.
Change of phase, J.
Radiation, K.
Liquid metals, L.
Low-density heat transfer, M.
Measurement techniques, N.
Heat exchangers, P.
Aircraft and space vehicles, Q.
Thermodynamic and transport properties, R.

CONDUCTION

Transient heat conduction commands the attention of a large number of investigators. Pratt [37A] presents exact solutions for heat conduction through walls of cavity construction for isothermal boundary conditions on one wall and sinusoidal or step variations of surface temperature on the other. Halle [14A] describes an exact solution of the simple, one-dimensional, semi-infinite system problem with variable thermal properties. Integral heat balance techniques are advocated by Thorsen and Landis [48A] for direct attack on one-dimensional systems having non-uniform initial temperatures. By changing the parameters of the published (graphical) data for infinite plates exposed to a sudden change in environment temperature, Bump [6A] replots the data to establish conditions where thick plates (or those subjected to short exposure times) may be treated as semi-infinite solids. Lindholm *et al.* [25A] supply pure radiant thermal energy (1000 cal/cm^2 s) to generate temperature profiles matching theoretical predictions. Geometrical considerations mark the studies of Palinski [34A] who treats the hollow cylinder with time-dependent ambient temperature and surface heat supply, Phythian [36A] who considers the heating of the cavity inside a spherical shell satellite, and Raychaudhuri [38A] who deals with the transient thermal response of enclosures. Laura and Chi [21A] apply conformal mapping to a three-dimensional, unsteady, heat-conduction problem. For prescribed heat flux on all boundaries of infinite regions of arbitrary geometry, with time dependent (spatially distributed) heat sources and arbitrary initial conditions, Ölçer [33A] gives general expressions for the temperature distribution. Transient heat flow for composite systems characterizes the work of Giere [11A] who considers two layers in perfect thermal contact, Bulavin and Kashcheev [5A] who work with arbitrary heat sources in symmetrical, multi-layered bodies, and Heasley [15A] who obtains approximate solutions for the heat flow between contacting solids in terms of contact geometry. Analogue procedures concern Stops [42A] in his description of a novel iterative device to study one-dimensional heat conduction with various boundary conditions and Zerkle and Sunderland [53A] who obtain the temperature distribution in a slab subject to thermal radiation by a thermal-electrical analog computer. The application of control engineering principles is illustrated by Zermuehlen and Harrison [52A] in their study of room temperature response to sudden heat inputs.

Moving boundaries are considered in a variety of circumstances: freezing front motion and heat transfer outside an infinite, isothermal cylinder [46A], transient temperature in slender moving bar comprised of composite materials in intimate contact [54A], phase changes in rods and infinite media arising from plane heat sources [17A], and comments [2A, 3A] on a pseudo-steady-state approximation for moving boundary problems. Griffin and Coughanowr [12A] analyse phase boundary motion in diffusion-controlled processes by three general methods.

Steady-state problems are represented by the works of Peavy [35A] who analyses two-dimensional heat conduction in an exposed exterior column of rectangular cross-section, Vodicka [49A] who considers the homogeneous, isotropic, infinite solid bounded internally by a circular cylinder, Rollinger [39A] who gives one-dimensional temperature distribution in convectively cooled thermoelements with variable cross-sectional area, and Lebedev and Skal'skaya [22A] who investigate heat conduction in wedge-shaped bodies. Mueller and Malmuth [30A] consider the temperature distribution in thin shields subject to longitudinal conduction in the presence of radiative exchange.

Fin efficiency for simultaneous heat and mass (evaporation) transfer is considered by O'Brien and Turner [31A]: Haley and Westwater[13A] photograph four distinct modes of heat transfer occurring simultaneously from a fin in a boiling liquid (see Fig. 1). The influence of various physical effects on heat conduction is described in papers by Lee and Richardson [23A]: sonic effects on heat transfer from a horizontal cylinder, Beliakov *et al.* [1A]: collision of metal bodies and associated thermal phenomena (a photographic study), Svergunenko [45A]: solid body deformation under the joint influence of diffusion and heat conduction, Sih [40A]: temperature distribution in bodies containing lines of discontinuity, and Sugiyama *et al.* [44A]; effect of heat flow on crystal transformation. Thermoelastic considerations concern Zaker [51A] in his study of stress-wave generation in a linear thermoelastic solid by internal heat addition and Ling and Mow [26A] in their investigation of the surface displacement of a convective elastic half-space under an arbitrarily distributed fast-moving heat source of constant velocity.

Joulean heating in electrically conducting solids is dealt with by Joseph [19A] in his consideration of the effect of nonlinear dependence of electrical resistance on the temperature distribution and Strassacker [43A] as he considers approximate solutions to the differential equation for the stationary temperature in wires of medium length.

Rather special circumstances distinguish the studies by Libby and Chen [24A] on growth (and temperature distribution) in a deposited layer on a cold surface; Mikhailov [28A] on heating of a two-layer plate; Stickler [41A] on thermal response of a metal slab to a class of radically dependent heat inputs; Horvay [16A] on time variation of mean temperature and slab thickness during the dipforming process; Todoroff [47A] on evaluation of critical diameter of pipe insulation (or thickness) for maximum heat transfer to an insulated pipe; and Masket [27A] on time reversal in heat conduction.

Mathematical techniques useful for solution of conduction problems appear in different contexts. Mitchell and Fairweather [29A] examine two implicit difference methods for solving two-dimensional, transient, heat conduction; Gay [10A] evaluates the suitability of a number of approximate methods for solving transient heat conduction with radiation boundary conditions; Winer [50A] presents distinctive solutions to the complete conduction heat-flow equation; Lardner [20A] uses Biot's principle on one-dimensional problems with nonplanar geometry, and Emery [9A] uses Biot's variational technique to solve a class of heat conduction problems. Improved point-matching techniques are described by Ojalvo and Linzer [32A] and Churchill [8A] presents a scheme for constructing general solutions for all ranges of variables and parameters from solutions for a few, limiting, special cases. Brogan [4A] gives a simple numerical solution for heat conduction in a solid with a receding surface.

Two works deal with conductive aspects of measurements. Jones and Hunt [18A] use an improved technique for obtaining quantitative aerodynamic heat-transfer data with surface coating materials. Chao [7A] analyses end wall heat transfer in a rarefraction wave tube, with results which appear to confirm the validity of the thin thermal boundary layer assumption used.

CHANNEL FLOW

Research on turbulent heat transfer in tubes and ducts continues to be primarily experimental in character; on the other hand, for laminar flows, most of the published investigations are analytical. The forthcoming discussion will first be concerned with turbulent flows and later with laminar flows.

Large variations in the thermodynamic and transport properties of a flowing fluid may be caused both by large wall-to-bulk temperature differences and by operation of the system near the critical state. Experiments involving turbulent gas flows in tubes at high ratios of wall-to-bulk temperature have been concerned with methods of correlating the resulting Nusselt numbers. Studies making use of pre-cooled helium and hydrogen have achieved wall-to-bulk temperature ratios of 8 [58B]; the same approach, but with nitrogen as the working fluid, yielded a temperature ratio of 7·5 [44B]. Special consideration has also been given to large temperature ratios (but somewhat lower than the aforementioned) in the downstream region of a tube (i.e. beyond the entrance region) with air, helium, and nitrogen as the flowing fluids [37B]. The Nusselt number results, when evaluated using bulk fluid properties, fell about 30 per cent below the Dittus–Boelter equation. Experiments on the effects of temperature ratio were also performed for a concentric annular duct with heat transfer at the inner bounding wall only [34B]. Turbulent flow studies near the critical point were carried out using hydrogen [15B], water [56B], and Freon 12 [17B] as working fluids. In the first two of these investigations, satisfactory correlation of the Nusselt number is achieved by employing a modified form of the Dittus–Boelter equation; however, this type of correlation was found to be inadequate for the Freon data. Visual observations during the latter investigation suggested the existence of a boiling-like process near the critical state.

The periodic squashing of a tube wall leads to an increase in the turbulent heat transfer, with the most marked increase (a factor of 3) occurring in the Reynolds number range from 2300 to 4000 [16B]. Artificial roughness, introduced by threading the inside wall of a tube, may also increase the heat-transfer coefficient, but a penalty in pressure drop is sustained. Information on the effect of such roughness is provided by experiments involving air, water, and a glycol [27B, 51B]. It is suggested that for a high Prandtl number fluid, the heat transfer per unit pressure drop for a rough tube is higher than for a smooth tube [51B]. The superposition of a resonant sound field upon a steady through-flow in a tube may cause spatially varying local heat-transfer coefficients along the length of the tube [24B]. Ultrasonic vibrations, induced by a transducer mounted on the outer wall of an annular test section with heated inner tube, gave rise to increases of up to 40 per cent in the heat-transfer coefficient [3B].

Measured heat-transfer rates in a supersonic parallel-walled diffuser were substantially higher

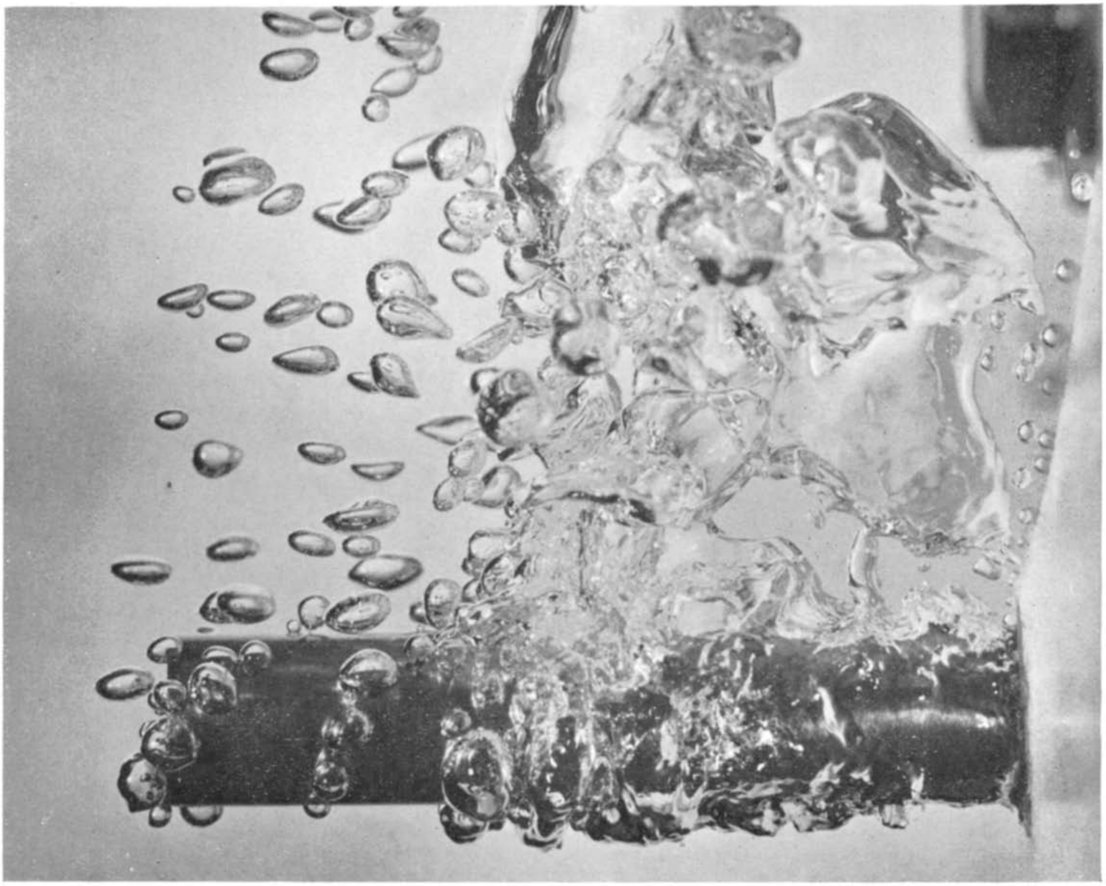

FIG. 1. Heat transfer from a 0·25-in. dia. copper fin to boiling isopropanol consists of four distinct modes of heat transfer occurring simultaneously: film boiling at the hot end (right-hand side of photo), transition boiling next to it, nucleate boiling in the center region, and free convection near the cold end [13A]

than those predicted by standard pipe-flow correlations [2B]. In a rectangular duct in which one wall is heated and also moves parallel to the flowing airstream, the minimum value of the heat-transfer coefficient occurs when the relative velocity of the wall and the airstream is zero [36B]. New measurements are reported of the energy separation and of the velocity and temperature fields in a vortex tube with air as the working fluid [57B]. A sequence of publications provides information on various aspects of heat transfer and fluid flow in helical and spiral coils for both the turbulent and the laminar regimes [20B–32B]. It is well established that heat-transfer coefficients in the thermal entrance region exceed those for the thermally developed region. A correlation, based on experimental data, has been devised for relating the average coefficient for any length of duct to the fully developed coefficient [1B].

An analysis of turbulent heat transfer in tubes at high Prandtl numbers employs a model wherein all transverse transport processes for heat are confined to the viscous sublayer [26B]. For the Graetz problem in an annulus having an isothermal inner wall and a uniformly heated outer wall, the WKB method is employed to determine the higher eigenvalues [65B]. The method applies to laminar flow as well as to turbulent flow. The effect of a transverse mass transfer on fully developed heat transfer in a parallel-plate channel (blowing and suction of equal magnitudes at the opposite walls) was correlated as a unique function involving the dimensionless transverse velocity and the no-blowing Stanton number [35B]. The transient heat transfer for flows with quasi-steady heat-transfer coefficients is analysed for various degrees of refinement of the transient conduction problem in the tube wall [11B, 14B]. In the latter study, both heat capacity and *radial* conduction were accounted for.

For laminar flow, the effect of large differences between the wall and bulk temperatures has also been studied. Numerical finite-difference solutions, carried number–Graetz number relationship is little affected by the property variations provided that bulk properties are used in the foregoing groupings [4B, 63B]. The latter investigation is also concerned with the threshold of free convective effects. Heating experiments involving nitrogen and helium flowing in a circular tube reaffirm the aforementioned findings of analysis relevant to the variable property effects [9B].

The Graetz problem, which is concerned with the thermal development of an already hydrodynamically developed flow, continues to be of interest in the laminar regime. The thermal development in a tube corresponding to the classical boundary conditions of uniform wall temperature, uniform wall heat flux, and linearly varying wall temperature has been re-solved, this time by a finite-difference method [13B]. For the more general case in which the outside surface of the tube loses heat to the surroundings, the thermal entrance region is longer than that for uniform wall temperature [49B]. The eigenvalues and eigenfunctions corresponding both to Poiseuille flow and slug flow have been computed for the case of a sinusoidal distribution of heat flux along the tube wall [19B]. Experiments involving a heat-generating fluid (dilute aqueous sodium chloride) flowing in rectangular ducts of aspect ratio 1:1, 4:1 and 8:1 were correlated with predictions for the parallel-plate channel by using the half-length of the short side as the characteristic dimension [55B].

A mass-transfer problem with a first-order chemical reaction within the fluid is similar in form to a thermal Graetz problem wherein there is an internal heat source in the fluid [18B]. The Leveque model, applicable in the region just downstream of the onset of heating, has been applied to the uniform heat flux problem [8B]. Two interesting generalizations of the Graetz problem have been investigated. In one case, the velocity field corresponds to a Couette flow with a pressure gradient, i.e. a combination of a Couette flow and a plane

Poiseuille flow [20B]. In the second case, heat is exchanged between two countercurrently flowing streams [42B].

More and more attention is being given to problems wherein the velocity and temperature fields experience a simultaneous development along the length of the duct. For the circular tube, solutions have been obtained by the following methods: (a) The conservation equations are approximated by their integral forms and the velocity and temperature profiles are expressed as polynomials [45B]. (b) The velocity field is locally approximated by a Levêque-type straight-line representation, permitting the energy equation to be solved analytically [59B]. The solution is purported to be applicable to high Prandtl number flows. (c) The velocity field is taken from the Langhaar solution and the energy equation is solved by finite-differences [61B, 62B]. Solutions of the simultaneously-developing velocity and temperature fields in a parallel-plate channel have been obtained both by finite differences [21B] and by an integral method [41B]. The latter investigation also took account of internal heat generation in the fluid.

For a slug flow, the thermal development within the fluid was solved simultaneously with the heat-conduction problem in the wall [6B]. The slug flow model was also employed to investigate the effects of axial conduction in the fluid during a thermal transient [7B]. The solutions demonstrate that the axial conduction effect is smaller during the transient period than in the steady state.

Attention is now directed to fully developed laminar heat transfer. Complex variable methods are shown to be applicable for solving rather general duct cross sections when the axial temperature gradient is linear [46B, 47B]. The identity in form between the governing equations for a simply supported, uniformly loaded plate and the fully developed temperature field in a duct is pointed out. It is then proposed that the Moiré method, previously applied for the former problem, now be also used for the latter [5B]. Results for Nusselt number, friction factor, and incremental pressure drop for triangular and circular sector ducts are graphically presented and compared [53B]. It is demonstrated that the Nusselt numbers for flow in diverging and converging plane-wall passages are respectively lower and higher than that for a parallel-plate channel [54B]. A solution of the energy equation for Stokes-type flow through a conical passage has also been obtained [10B].

The temperature distribution in the heat-generating walls of a rectangular duct bonding a thermally developed laminar flow is studied with a view to discerning the extent of the hot spot temperature [48B, 50B]. It is shown both analytically and experimentally that the laminar heat-transfer coefficient for a curved pipe exceeds that for a straight pipe [40B]; this effect is accentuated at higher Prandtl numbers. A comparison between hydrogen and air as mass-transfer coolants in a porous circular tube reveals that the former is far more effective [43B]. The thermal boundary conditions consistent with similarity solutions in logarithmic spiral flows are delineated [64B].

Several papers are concerned specifically with the effects of viscous dissipation. Finite-difference solutions are reported for both the parallel-plate channel [22B] and the circular tube [12B]. In the latter investigation, corroborating experiments were performed, and it was demonstrated that viscous heating could significantly reduce the apparent viscosity measured by a capillary viscosimeter. The effects of viscous dissipation on measurements with a cone-and-plate viscosimeter were modelled by consideration of Couette flow; the analysis was performed for a pair of non-Newtonian fluids [60B]. The flow in a slider bearing was modelled as a flow in a channel of varying height. The temperature distribution across the flowing film (generated by viscous dissipation) is shown to be capable, through its effect on the viscosity, of influencing the load capacity of the bearing [52B]. The conductions under which viscous dissipation and variable viscosity preclude steady, fully developed laminar flow solutions in channels and tubes are delineated [25B].

Several solutions for thermally developed non-Newtonian flows have been carried out. These include the Ellis fluid [39B], a visco-elastic fluid [38B], a Bingham plastic [33B], and a power-law fluid [23B]. The latter investigation was specifically concerned with the response of the flow to arbitrary circumferential variations of the thermal boundary conditions.

BOUNDARY-LAYER FLOW

Boundary-layer theory and solutions

There is continuing interest in solution methods for laminar and turbulent boundary-layer flows. A computer-oriented solution method for the laminar compressible boundary layer with heat transfer employs a finite-difference representation for the streamwise derivatives, thereby leaving ordinary differential equations to be solved in the transverse direction [42C]. Generalized integral procedures have been devised for solving the compressible laminar [23C, 46C] and turbulent [46C] boundary layers with heat transfer and variable fluid properties. For flow along a flat plate, methods are presented for finding the surface temperature distribution corresponding to a prescribed surface heat-flux distribution either under laminar [22C, 43C] or turbulent conditions [43C]. The formulation of reference [43C] is employed in solving the problem of simultaneous convective and radiative heat transfer. Various existing calculation methods are compared with experimental results for heat transfer to turbulent boundary layers with variable free-stream velocity; it is found that none of the methods provides fully satisfactory predictions [2C].

Laminar boundary layers have been subjected to further study. A unified treatment of two-dimensional forced and free convection flows deduces the body shapes and allowable thermal boundary conditions that are consistent with similarity solutions [37C]. It is demonstrated that the well-known Crocco solution for the compressible energy equation for $Pr = 1$ can have an additive term proportional to the transverse velocity gradient when fluid properties are constant [28C]. The effect of a spatially linearly accelerating or decelerating free-stream velocity is to respectively increase or decrease the local Nusselt number [5C]. Solutions are reported for the case of distributed heat sources (either uniform or temperature dependent) in a flow adjacent to a flat plate with suction [35C, 36C]. Nusselt numbers for the laminar boundary layer with large Peclet numbers and small or moderate Reynolds numbers are derived as first-order corrections to existing results [1C].

Some consideration has been accorded to variable property effects. A pair of papers treat the inviscid flow over a flat plate [19C, 39C]. In the first of these, an approximate analytical expression that can accommodate any variation of the fluid properties is derived for the case of the cold wall. The second is concerned with density variations described by the perfect gas law. The effects of deviations of Pr and ω ($\mu \sim T^{\omega}$) from unity on laminar and turbulent skin friction have also been investigated [49C].

A study of unsteady stagnation-point heat transfer shows that the time required to achieve steady state following a step change varies directly with $Pr^{\frac{1}{4}}$ and inversely with the free-stream velocity [7C]. From a simultaneous transient solution of the stagnation-point thermal boundary layer and the heat conduction in the adjacent wall, it is found that the time-variation of the wall temperature is essentially identical to that computed by using a quasi-steady heat-transfer coefficient [26C]. Linearized solutions of the unsteady boundary-layer energy equation were obtained for cases where either the wall temperature or the wall heat flux vary with time [34C].

A cylindrical wall jet is formed by axial flow along a cylinder located in an otherwise quiescent environment. The heat transfer to such a flow is analysed under the condition that the boundary layer thickness is small compared with the cylinder radius [40C]. A radial jet may be defined as a radial outflow of a fluid layer along a wall. Temperature solutions for the radial jet were carried out for those conditions which yield similar velocity solutions [8C]. Study is made of the downstream boundary layer development of an initially parallel flow bounded on one side by a plate and on the other side by an outer flow in which there is an already developed boundary layer (i.e. slot injection of a gas). The existence of the already developed outer boundary layer can have an important effect on the downstream heat transfer at the wall [38C].

The presence of a protuberance in a hypersonic turbulent boundary layer can significantly increase the heat-transfer coefficient in the neighborhood of the protuberance [45C]. An effect of blunting the tip of a cone in hypersonic flow is to significantly decrease the local boundary-layer heat transfer and skin friction [48C].

Dissociation, ionization, and chemical reactions

An analysis studies the effect of variable transport properties on a dissociated self-similar boundary layer with surface reaction [17C]. For high altitude hypersonic flight, it was found that the result of a calculation with an accurate description of the transport properties may differ from one with simplified relations up to 60 per cent. A model using Lighthill's assumption, that the velocity is proportional to the wall distance, gives the possibility to obtain an analytic solution to the equations describing a similar boundary layer with finite recombination rate at the wall [15C]. An analytic solution by Freeman and Simpkin based again on Lighthill's assumption has been extended to include a varying gas temperature and varying surface properties [41C]. Correlations of solutions describing heat transfer in near equilibrium stagnation point boundary layers are offered for rapid calculations [44C]. A simplified analysis to a multi-component laminar boundary layer with frozen or equilibrium chemistry has been based on the local similarity assumption [6C]. Measurements have been performed on the gaseous system $N_2O_2/2NO$ dissociating in the boundary layer on a horizontal tube in free and forced convection [3C]. Heat-transfer coefficients defined either with a total enthalpy difference or with a heat conduction potential difference are little influenced by the dissociation process. An analysis of heat transfer from a non-equilibrium turbulent boundary layer to a catalytic surface includes the effect of thermal diffusion and of variable wall catalytic effect [21C]. It was found that heat transfer increases up to 150 per cent with a change of the catalytic parameter by a factor 100. Inclusion of thermal diffusion decreased heat transfer by a maximum of 18 per cent.

Stagnation point convective heat transfer in partially ionized air was measured in a hypervelocity free-flight facility at velocities of order 4×10^3 ft/s [10C]. The results agreed reasonably with Hoshizaki's analysis. Heat transfer to surfaces exposed to a partially ionized air stream in a shock tube at simulated flight velocities of order 50000 ft/s was also measured with an infrared heat-transfer gage [33C]. The results support previous measurements with thin foil heat transfer gages and an analysis by Fay and Kemp. Heat transfer to wires in a partially ionized argon plasma, with up to 75 per cent ionization, heated by an electric arc, is reasonably well described by relations mentioned in the preceeding sentences [18C].

Boundary layers were found to be near the frozen state with electron temperatures possibly somewhat higher than the gas temperatures. Melting ablation on decelerating spherical bodies of glassy material was studied analytically and experimentally [30C]. The measurements were carried out in a vertical tunnel with gravity replacing the deceleration forces.

Effect of magnetic and electric fields

The flow field on a flat surface exposed to a uniform parallel stream and a uniform magnetic field parallel to the stream can be subdivided into three regions: potential flow, an inviscid layer with MDH effects, and a viscous sublayer. The thermal boundary layer for such a flow is studied for large magnetic Reynolds numbers, small magnetic Prandtl numbers, and a flow Prandtl number of order one [14C]. The same flow and electric field geometry on an electrically insulating surface has been analysed to calculate recovery temperatures and heat transfer. [32C]. The accuracy of integral methods to analyse MDH boundary layers was investigated [16C]. The method, when properly applied, was found acceptable for laminar and turbulent boundary layers. The integral method of Kármán–Pohlhausen has been applied to magnetohydrodynamic flow in the entrance section of a channel with transverse magnetic field [12C]. Heat transfer was found to increase with Hartman number, especially at high Prandtl numbers. The treatment of one-dimensional magnetohydrodynamic flow can be simplified by the use of thermodynamic state diagrams [24C].

The radiative flux from a shock-heated argon plasma to the stagnation point of a blunt body was measured and found to agree with semi-empirical predictions [4C]. The spectral characteristics of the radiation were found to be very complex and more experiments will be necessary to gain a complete understanding. The radiant energy loss from a plasma seeded with 0·1 per cent cesium at 1 atm and 2000°K was carefully analysed [25C]. It was found that consideration of two principal resonance lines only can approximate the result satisfactorily. An electric arc between a rod-shaped cathode and a plane wall serving as anode with superimposed flow parallel to the wall exhibits rapid fluctuations under certain conditions [31C]. The onset of these fluctuations is essentially determined by a critical Reynolds number or Péclet number. The temperature field in a free-burning arc with transpiration-cooled anode was determined spectroscopically [11C].

Experimental studies

Experiments on heat transfer to a turbulent boundary layer with varying free-stream velocity and varying surface temperature established the fact that acceleration suppresses turbulence and decreases heat transfer [29C]. The local Stanton number St in accelerated flow to the Stanton number St_0 in a corresponding boundary layer with constant velocity is described by the relation

$$\frac{St}{St_0} = 1 - 165\frac{K}{St}, K = \frac{\nu}{u_\infty^2}\frac{du_\infty}{dx}$$

Measured stagnation point heat-transfer coefficients on ellipsoids of revolution were found to agree with the theory by Felderman and Fellinger [13C]. A technical note reports on measurements of convective heat transfer on various models (sphere cylinder, blunted cone, re-entry shapes) exposed to air, nitrogen, carbon dioxide and argon in a combustion-driven shock tunnel at 3300 to 5400 Btu/lb gas enthalpy [27C]. The results agreed with analytical relations with argon producing heat transfer by approximately 30 per cent higher than the other gases. Heat transfer and recovery temperature were measured on a thin plate in hypersonic flow at small Reynolds numbers [20C]. A similar study was concerned with heat transfer over an 80 deg swept delta wing in hypersonic flow at a Mach number 9·6 [47C]. The local heat flux to a water film flowing down a vertical surface was investigated experimentally [9C].

FLOW WITH SEPARATED REGIONS

Single bodies

A previous relation describing heat transfer to cylinders in cross flow has been extended to low Reynolds numbers [23D]. The relation

$$Nu = 0{\cdot}3737 + 0{\cdot}37\, Re^{\frac{1}{4}} + 0{\cdot}057\, Re^{\frac{3}{4}}$$

was found to describe heat transfer in the Reynolds number range from 1 to 10^5. It is conjectured that the term with $Re^{\frac{1}{4}}$ describes heat transfer to the laminar boundary layer and the term with $Re^{\frac{3}{4}}$ expresses heat transfer to the downstream portion of the sphere. Similar relations have been found to describe the results of measurements of heat transfer from a cylinder to water in cross flow [10D]. Fluctuations in the velocity of an air stream can increase heat transfer to a perpendicular cylinder up to a factor 2·2, depending on frequency and amplitude [22D]. Experiments indicate that heat transfer between air and a cylinder in cross flow at Reynolds numbers between 0·02 and 10^3, and Mach numbers larger than 0·2 exhibits a smooth transition from continuum flow in which it is proportional to the square root of the Reynolds number to free molecular flow with a Nusselt number proportional to Reynolds number [8D]. Heat transfer was measured on small wires located within the boundary layer surrounding a cylinder [7D]. It appears that the temperature gradient normal to the wire has no significant effect on this heat transfer.

The results of measurements of heat and mass transfer from a single sphere to a fluid could be described for Reynolds numbers between 20 and 2000 by the equation [24D]

$$Nu = 2 + B\,Pr^{\frac{1}{3}}\,Re^{\frac{1}{2}}$$

For mass transfer, the Sherwood number *Sh* replaces the Nusselt number *Nu*, and the Schmidt number *Sc* replaces the Prandtl number *Pr*. The constant *B* has the value 0·69 for air and 0·79 for water. Comments to the preceeding studies are made in reference [17D]. Heat transfer from a free stream flowing over a transverse rectangular notch at velocities between 160 and 600 ft/s was found to be proportional to the product freestream density times free-stream velocity to the power 0·8 and to the ratio of notch length to notch height to the power −0·2 [11D]. Measurements on the same configuration emphasized the influence of the free shear layer on the heat transfer to the notch surface [25D]. Convective heat transfer was also measured in flow normal to banks of tubes [1D]. Local heat transfer on a surface exposed to an impinging jet was correlated to the local turbulence intensity [13D]. The turbulent wake behind a heated cylinder was investigated [14D].

Packed and fluidized beds

Effective conductivities and wall film heat-transfer coefficients were measured for a packed bed with a fluid filling the empty spaces [21D]. The bed was arranged between an upper steam-heated and a lower water-cooled wall. From a review of previous experiments, it was concluded that the turbulent heat conductivity in flow direction has a strong influence on heat transmission between a wire gauze and a gas flowing through it [4D]. Measurements of heat transfer and pressure drop for hydrogen and nitrogen, flowing through a tungsten wire mesh with 64–72 per cent porosity, at temperatures to 5200°R, were investigated [26D] because of the applicability to nuclear rocket developments. Experimental results on heat transfer between air and spherical or cubical particles forming a packed bed could be presented in an illustrative diagram which included also heat transfer for laminar boundary-layer flow over a flat plate and for laminar tube flow [18D]. The characteristic length contained in the Nusselt and the Péclet numbers has to be specified appropriately for each configuration, the characteristic velocity is the actual velocity through the free spaces. Concurrent gas and liquid flow through packed beds experiences, under certain conditions, pulsations of the gas which increase radial heat transfer through the bed up to 400 per cent [28D]. Condensation and adsorption in gas condensate mixtures flowing through porous media can reduce the permeability increasingly with increasing pressure [9D]. Equations developed for mass and heat transfer in a porous medium by Luikov and Mikhailov have been modified to include molar (hydrodynamic) transfer [19D]. An extensive review of the literature on heat transfer in packed beds, including 244 references, points out that there is still a lack of data in many areas [2D].

A similar review including 242 references

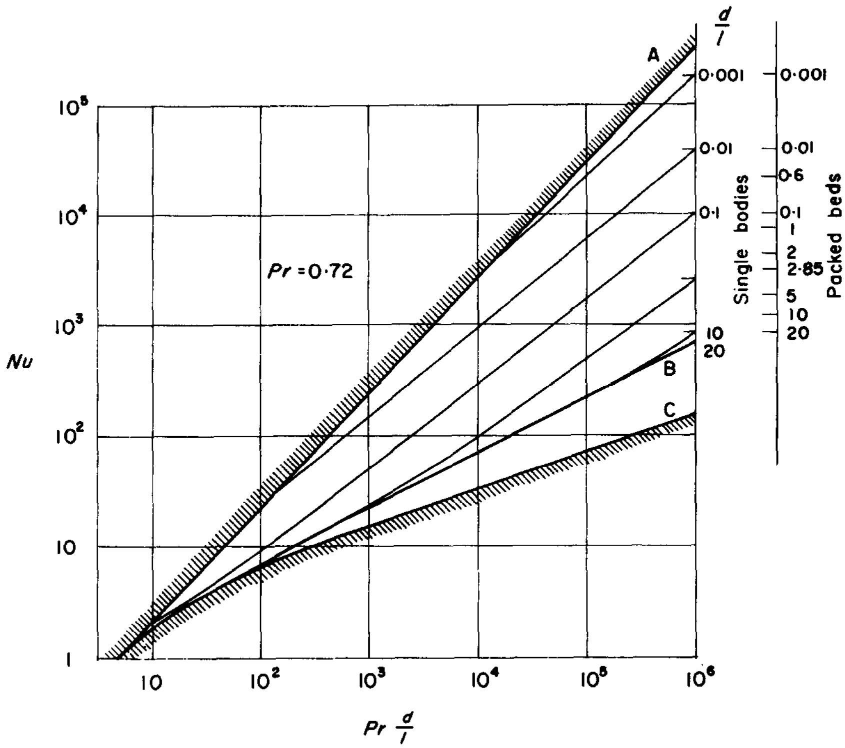

FIG. 2. Nusselt numbers for single bodies, for ducts, and for packed beds [18D]. $Nu = hd/k$, $Pe = vd/\alpha$, h based on entrance conditions, d hydraulic diameter, v velocity in smallest cross-section, l length of object measured along surface in flow direction, each layer is considered separately in packed beds. A complete temperature equalization, B laminar boundary layer, flat plate, C laminar tube flow.

treats heat transfer in fluidized beds [3D]. Charts illustrating the results exhibit an extensive scatter of the data obtained by various investigators, indicating the complexity and our limited understanding of this process. The results of measurements on particle-to-liquid heat transfer in a water-fluidized system with stainless steel or lead spherical particles, heated by induction, could be represented by the following equation for Reynolds numbers between 240 and 14000 [15D]

$$Nu_p = 1{\cdot}28 \times 10^{-5} (Re_p F)^2 Pr^{0{\cdot}67} \times \left(\frac{D_T}{D_p}\right)^{0{\cdot}5} \left(\frac{\rho_f}{\rho_p}\right)^2 \left(\frac{\mu}{\mu_0}\right)^{0{\cdot}83}$$

F indicates a velocity correction factor as a function of porosity, D denotes the diameter. The index T refers to the tube, p to the particles, and f to the fluid. An analytic model to describe the mechanism of wall-to-fluid heat transfer in fluidized beds was based on particle velocities and on the radial temperature profile [27D]. Combining experimental results with this model, it was concluded that particle convective heat transfer contributes 50–60 per cent to the total heat transfer when the thermal resistance of the particles is small relative to the resistance of the fluid film, and 30–40 per cent when both are of the same order of magnitude. Effective thermal conductivities describing lateral heat transfer in a fluidized bed were measured in reference [12D] and relations for the thermal diffusivity were established [6D]. Wall-to-bed heat transfer was also experimentally determined as a function of Reynolds number for hematites and pyrites fluidized in air [5D]. The effective thermal conductivity for a fluidized system moving through a packed bed was up to four times larger for cylindric bodies than for spheres forming the packing [29D]. The packing was made up of copper, glass, or steel particles. The fluidized system consisted of glass beads in air. The pressure drop for flow of a gas solid mixture can be calculated with an analytic model which uses a modified eddy diffusivity related essentially to the total gas and solid mass flow [16D]. Fundamental relations for heat transfer of fine dispersion flows have been reported [20D].

TRANSFER MECHANISMS

Experiments established the influence of local surface roughness and of free-stream turbulence on boundary layer transition in supersonic flow over a cone [15E]. The roughness consisted of a lateral row of spheres. It is also shown that a small increase in the plasticity of a non-Newtonian fluid delays transition significantly. A surface hot film probe was used to detect transition in the boundary layer at Mach numbers between 1·3 and 4 [8E]. With increasing Mach number, it became increasingly difficult to fix the transition point by a distributed roughness. No transition reversal was observed in a hypersonic highly cooled boundary layer at $Ma = 10$ and $T_w/T_0 = 0{\cdot}75$ to $0{\cdot}365$ [11E]. Laminar and turbulent heat transfer could be represented by incompressible relations with properties at a reference enthalpy.

A fluctuating flexible wall was placed into a low turbulence wind tunnel to investigate whether instability waves within a boundary layer could be damped by the vibration of the wall [16E]. Drastic reductions of the velocity fluctuations in the boundary layer could be achieved when the wall vibrated in phase with the velocity fluctuations. Flow visualization with suspended metallic particles gave qualitative as well as quantitative information on transition in circular Couette flow [3E]. An analysis demonstrates that vortices in a two-dimensional stagnation flow amplify by stretching when the vorticity scale is sufficiently large. They increase in this way the heat transfer whereas the wall shear is little affected [13E].

The following single equation is found to describe the universal turbulent velocity profile well up to $y^+ = 1000$ [2E].

$$y^+ = u^+ + (u^+/8{\cdot}74)^7$$

u^+ and y^+ denote velocity and wall distance made dimensionless with the wall-shear velocity. An expression for the turbulent diffusivity was established as a function of the fundamental frequency and the intensity of the turbulent fluctuations for flow through very rough tubes at Reynolds numbers between 10000 and 135000 [14E]. The results of new measurements were compared with the velocity defect law derived by Mickley and by Stevenson [10E]. A hot film probe was used to measure Eulerian turbulence parameters for water flowing through a pipe [9E]. The obtained parameters were correlated with Reynolds number, eddy diffusivity, and Lagrangian turbulence parameters. Conditions that the eddy diffusivity concept and turbulent velocity profile expressions impose on one another were analysed and 13 such constraining conditions were established [12E]. Measurements determined how the turbulent diffusivity varies radially in a compressible turbulent jet exhausting into a stream with uniform velocity [17E]. Measurements also established the local eddy diffusivity for momentum and heat in the wake behind heated two-dimensional objects [1E]. Transport processes in the wake of a sphere at Reynolds numbers smaller than 410 were found to be similar to stagnation point flow [7E]. Statistical analysis applied to uniform shear flow established relations between the turbulent statistical correlations and the empirical transfer parameters [4E, 6E]. The complete system of non-dimensional similarity parameters for flow and heat transfer was tabulated and discussed [5E].

NATURAL CONVECTION

Research activity continues at a lively pace in a wide range of problem areas involving natural convection. In particular, problems of convective instability and the consequent fluid motions and heat transfer have elicited interest among investigators from many branches of engineering and applied science.

Attention is first turned to boundary-layer theory. The effect of appending the longitudinal conduction term to the boundary-layer energy equation for a heated vertical plate is to produce an upstream (i.e. downward) transport of heat at the leading edge; this gives rise to a sign reversal in the wall heat flux [48F]. When a vertical plate or cylinder undergoes a spatially uniform timewise change in wall temperature or wall heat flux, a finite time elapses before a regime of purely conductive heat transfer in the adjacent fluid gives way to a convective regime. The duration of the conduction regime is related to the time required for fluid to move from the leading edge to the point of interest [26F]. Solutions for the vertical cone [30F] and the horizontal cylinder [32F] with power-law surface temperature variations have been added to the store of boundary-layer solutions; in the latter case, similarity does not exist and a series method is employed. It is also demonstrated that similarity solutions cannot be attained for a power-law non-Newtonian fluid adjacent to a heated vertical plate with a power-law temperature variation [56F]. In the case of the horizontal plate, natural convection boundary-layer solutions are possible for a heated plate facing upward and a cooled plate facing downward [23F]. Combined natural convection and forced convection boundary-layer flows on vertical and horizontal plates [29F] and on wedges of various opening angles [27F] have been solved by series expansion methods.

Among various heated gases that were injected at the surface of a vertical flat plate into an air environment, the effects of variable fluid properties were most strongly manifested with helium and hydrogen [22F]. Solutions have also been obtained for time-dependent suction at the surface of a doubly-infinite heated vertical surface [55F] and for steady-state, spatially uniform blowing or suction in a vertical, flat-plate boundary layer [8F].

Several problems involving confined natural convection flows have been subjected to analysis. Among these is the fully developed flow of an electrically conducting fluid in a vertical parallel-plate channel subjected to a horizontal magnetic field [54F, 58F, 63F]. The first of these analyses pertains to transient conditions and the latter two to steady-state conditions. A study of the natural convection flow of a Bingham plastic in a vertical channel focuses attention on the effects of the rheological properties of the fluid on the velocity field [62F]. A finite-difference method is employed in solving the problem of natural convection in the annular space between two horizontal cylinders maintained at different temperatures [1F]. An open thermosyphon is a heated vertical tube, closed at the bottom and open at the top to a reservoir of cool fluid; the Rayleigh number–Prandtl number relationship marking the condition where convection begins to affect the pure conduction heat-transfer results has been derived [39F]. A method for calculating the non-steady regimes of natural convection in multi-loop piping circuits was formulated, with special reference to nuclear reactor transients [2F]. Research in natural convection performed since 1946 by G. A. Ostroumov at Perm, U.S.S.R. is surveyed and 113 references are cited [43F].

Natural convection in confined spaces has also been studied experimentally. An investigation of the heat-transfer capabilities of open thermosyphons of various cross-section shapes reveals that the circular tube is the most efficient in the laminar regime; however, in the turbulent regime, the relative capabilities of the different cross-sections depend on the magnitude of the Rayleigh number [37F]. The closed thermosyphon is defined as a closed vertical tube, the lower portion of which is heated and the upper portion of which is cooled. This configuration has been subjected to a wide-ranging experimental study in which various flow regimes were identified and Nusselt number results were obtained [4F]. The closed thermosyphon configuration was also utilized in studying transport processes in carbon dioxide near its critical state; tests were additionally carried out at various angles of tube inclination. As the critical state was approached, the effective thermal conductivity achieved values as high as 10000 times that of copper [28F]. Heat-transfer experiments across plane fluid layers, oriented either vertically, horizontally, and at various angles of inclination, provided results covering the Prandtl number range from 0·02 to 30000 [13F, 16F]. A correlation has been devised which takes account of both the influence of natural convection and of variable fluid properties on laminar forced convection heat transfer in a horizontal isothermal-walled tube [50F].

Some experiments relating to external flows are also reported. When humid air fills the space adjacent to a cryosurface, simultaneous natural convection heat and mass transfer occurs, and frost forms on the surface. It has been demonstrated that the effect of the simultaneous mass transfer has a very small effect on the heat-transfer coefficients [3F]. Experiments involving a non-Newtonian power-law fluid adjacent to a heated vertical plate provide heat-transfer results that are in excellent agreement with theory [46F]. From tests involving an ensemble of vertically oriented fins of rectangular profile, it was found that the heat-transfer coefficients are lower than those for a corresponding vertical plate [61F]. An electrically heated horizontal wire was immersed in the non-equilibrium gaseous system $2NO_2 \leftrightharpoons 2NO + O_2$. Temperature differences of several hundred degrees centrigrade were required in order to affect an increase in heat transfer owing to the energy of the reaction [6F].

Several investigations have been concerned with the effects of acoustic fields and mechanical vibrations on natural convection. A standing sound field affects *local* natural convection heat-transfer coefficients for a horizontal heated cylinder at sound intensity levels considerably lower than that required to significantly influence the overall coefficient [44F]. A correlation of natural convection heat transfer for the horizontal cylinder in the presence of a standing sound field is devised which spans a wide range of sound intensities [34F]; it is suggested that the two participating processes are natural convection and convection due to acoustic streaming [45F]. Acoustically induced cavitation is also believed to play an important role [18F]. Vertical oscillations of a heated horizontal cylinder immersed either in water or in aqueous glycerine gave rise to significant increases in the natural convection heat-transfer coefficient [35F]. On the other hand, oscillations of a heated vertical plate in its own plane are found to have a small effect on laminar heat transfer [17F].

As was pointed out at the beginning of this section, problems involving convective instabilities have attracted wide attention. In the main, the research in this area is analytical; however, experimental investigations are also beginning to appear.

Among the experiments, an interferometer was employed to visualize the temperature for three distinct flow regimes in an air layer contained between horizontal parallel plates heated from below [25F]. For the same geometrical configuration, a combined experimental–analytical investigation concerned itself with the effect of two-dimensionality in suppressing turbulent convection (Rayleigh numbers from 10^5 to 10^7) [12F]. When a horizontal layer of fluid is cooled from above, as by surface evaporation, a nonlinear, time-dependent vertical temperature distribution is induced which may be subject to convective instability; this situation is studied both experimentally [19F] and analytically [20F]. Detailed measurements of the temperature field within a horizontal rotating layer of mercury, heated from below and cooled from above, provide insights into the nature of the flow field at various

Taylor numbers [24F]. For a vertical layer whose walls are maintained at different temperatures, velocity and temperature distributions for a variety of laminar flow regimes (including secondary flows) are measured and interpreted [14F]. In an extension of the aforementioned investigation, the wave motion leading to turbulence are described and measurements of the mean and fluctuating temperature field are carried out [15F].

There are a large number of analytical papers that deal with the conditions marking the onset of convective motion in various configurations that are heated from below. These include the spherical cavity [7F], the rectangular cavity with superposed vertical magnetic field [33F], the plane layer with a nonlinear basic temperature profile [60F], and with a time-dependent basic temperature profile [36F], the plane layer with a superposed magnetic field [53F], and the coreless induction furnace [10F]. For very thin plane layers that are heated from below, the convective motion is brought about by surface tension rather than by buoyancy. In such cases, surface active agents exert a strong stabilizing effect [5F]. When a layer of cold pure water rests on top of a layer of hot salty water, the system as a whole may be unstable even though the differences in density due to salinity are far greater than those due to temperature [59F].

Recent analytical papers have also treated nonlinear stability problems. A new method of studying the stability of general buoyant flows is based on energy considerations and accommodates nonlinear and time-dependent disturbances. It is found that there are no subcritical instabilities (i.e. instability at Rayleigh numbers lower than that of linear theory) for the plane layer problem with a basic linear temperature distribution [31F]. A conclusion similar to the foregoing was arrived at by employing alternative analytical methods [47F]. A necessary condition is deduced for the stability of steady-state solutions for the horizontal layer with vertical density gradient (opposite to gravity) vertical magnetic field and other vertical conservative forces [38F]. After instability sets in, a successive approximation method is employed in determining the finite-amplitude solutions for the flow field [49F]. An alternate approach to finding the motions after the onset of instability is to solve the governing (nonlinear) equations by a finite-difference method; this approach has been employed to provide details of the velocity and temperature fields in the range of Rayleigh numbers from the critical value to 10^7 [21F]. Further insights have been gained in explaining the tendency toward a hexagonal cellular pattern in the convective motion [51F, 52F].

The effect of externally forced motions on convective instability has also been considered, both in the case in which the entire fluid layer rotates [42F] and in which only the top bounding surface moves parallel to its own plane [11F]. For the laminar boundary-layer flow adjacent to a heated vertical plate, it is found that for Prandtl numbers in excess of five, the Grashof number marking the onset of instability varies as the third power of the Prandtl number [57F].

Buoyant motions are also of great interest in studies of air movement in the atmosphere. The effect of a constant source of heat, inserted at the base of a buoyant element, on the time-wise development of the element is studied by numerical integration [41F]. Radiative transfer in a turbulent buoyant plume reinforces a stable lapse rate in causing the plume to die out at a lesser height [40F]. The buoyant motion within a hot gas plume in a horizontal wind has also been investigated [9F].

CONVECTION FROM ROTATING SURFACES

A number of research papers has appeared encompassing rotating flows both without and with superposed forced convection.

It is demonstrated that bodies of revolution rotating about an axis of symmetry in an otherwise quiescent environment possess similarity solutions when the radius of revolution is expressed as a power of the streamwise coordinate [7G]. The energy equation also has similar solutions for power-law wall temperature variations. A somewhat parallel analytical treatment additionally considers internal heat generation in the fluid, but for simpler thermal boundary conditions [3G]. The exact solutions generated in reference [3G] were employed in constructing an approximate method for treating arbitrarily shaped bodies. Temperature distributions, including the effects of viscous dissipation, were derived for (a) a vortes flow normal to a plane surface, (b) a rotating disk in a fluid at rest, and (c) a solid-body rotation of a fluid above a fixed plane surface [12G].

For the rotating disk, series expansion methods are employed for solving the energy equation with and without viscous dissipation over a wide range of Prandtl number [17G]. A transient solution for an isothermal disk rotating in a low Prandtl number fluid shows that the time required to achieve steady state following an abrupt change in surface temperature varies as $1/Pr$ [2G]. The relative merits of various computation methods for turbulent heat transfer on a nonisothermal rotating disk are established by comparison with available experimental data [6G]. Laminar and turbulent heat-transfer predictions for the nonisothermal rotating cone are supported by experiments involving the sublimation of naphthalene [20G].

Simultaneous rotation and forced convection has been studied in a variety of configurations. Experiments involving the sublimation of naphthalene on a rotating disk with a normal approach flow suggest a computation model wherein transfer coefficients are predicted by a simple combination of the coefficients for stagnation-point flow and for pure rotation [10G]. Similar experiments performed with a rotating cone provide transfer coefficients in both the laminar and the turbulent ranges; a smoke technique is employed to visualize the flow field [18G]. Heat transfer from a rotating cone with a superposed axial free-stream flow has also been subjected to analysis by employing perturbation series for the limiting cases of slow and rapid rotation [21G].

On the basis of a turbulent boundary-layer model, Nusselt numbers are derived for flow passing from the center to the periphery between two rotating disks; various conditions of flow entry into the space are investigated [8G]. The reverse situation of radial inward flow has been studied both experimentally and analytically for the case where one disk is stationary, but satisfactory agreement was not achieved [13G]. Analytical consideration is given to a vertical tube, rotating about an axis parallel to itself, through which a fluid is pumped. The rotation induces a secondary flow in the plane of the cross-section, with a consequent increase of the Nusselt number [14G]. In another internal flow problem, an apparatus was constructed wherein a rotating tube separates two axially flowing fluids, one hot and the other cold [15G]. It was found that the heat-transfer coefficients were more affected by changes in rotation than by changes in the axial flow rate.

An analytical solution for a rapid, two-component chemical reaction on a rotating disk has been confirmed by experiments involving the neutralization of benzoic acid with sodium hydroxide [11G]. Heat-transfer rates from a rotating cylinder to decomposing nitrogen dioxide were measured; this reaction is characterized by a finite reaction rate [1G].

In an experiment involving a vertical rotating annulus of water with heating at the inner surface, the opposing effects of rotation and free convection lead at a minimum in the effective thermal conductivity [11G]. The effects of free convection on the stability of rotating flows has been investigated both experimentally and analytically. In a Taylor instability apparatus, i.e. a vertical annulus with inner (and perhaps, outer) rotating wall, the secondary motion at the onset of instability is not characterized by tordial vortices when radial temperature gradients are present [9G, 19G]. For a Couette flow with a lower heated plate, it is demonstrated that the principle of exchange of stabilities does not hold [5G].

When a vertical rotating annulus of liquid is subjected to a horizontal temperature gradient, several distinct flow regimes are possible. The transition between as axisymmetric and a non-axisymmetric mode has been investigated experimentally, with particular emphasis on the effect of viscosity [4G]. An analysis of the finite-gap Taylor instability problem with a radial temperature gradient employs a buoyancy force based on the centrifugal force field (gravity is neglected). A positive radial gradient is found to be destabilizing and a negative gradient stabilizing [22G].

COMBINED HEAT AND MASS TRANSFER

Subsonic film cooling using gas injection into a turbulent boundary layer on a flat plate is the concern of several studies. An extension of the assumption that the secondary fluid should be considered simply as a heat source (or sink) in the boundary layer indicates the parameters of importance in film cooling studies [15H]. A similar study includes a semi-empirical correlation for high tangential injection rates when the secondary gas acts somewhat like a wall jet [10H]. Experimental studies of film cooling with air as both the primary and injected gas indicate, over the range studied, that film cooling with injection through a porous section along the surface gives results similar to those obtained with tangential injection of the secondary gas [2H]. Film cooling with a high temperature mainstream of air and near tangential injection of secondary air has also been studied [7H].

The sublimation of graphite at hypersonic speeds [9H] and the effect of non-Newtonian flow in the liquid boundary of an ablating body's stagnation region [14H] are analysed. Measurements, with low speed flow, of the sublimation of carbon dioxide at an axisymmetric stagnation point do not agree well with theory [11H].

Two recent papers report results of analytical studies on laminar boundary layers with transpiration cooling, but neglect thermal diffusion effects. One [4H] concerns wall friction and heat transfer with variable free-stream velocity and compressible flow, while the other [18H] shows that effects of curvature cannot be neglected for axial flow over a porous cylinder. Analysis predicts the effect of suction on heat transfer in the stagnation region with heat sources or sinks present [8H]. The concept of the law of the wall and a velocity defect law are found useful in a study of turbulent boundary layers with wall suction or blowing [16H].

A number of studies, both analytical and experimental, treat binary boundary layers produced by transpiration through a porous surface. Experimental friction factors and heat-transfer results are determined in experiments in which various gases are injected into the turbulent boundary layer on a cone [6H], the mainstream Mach number varying up to 4·35. An analysis of a reacting laminar boundary layer with hydrogen injection indicates that earlier studies failing to include all the diffusional effects may be in error [5H]. Experiments show thermal diffusion significantly affects natural convection heat transfer when foreign gases are injected into the boundary layer [13H]. A recent review [12H] treats thermal diffusion effects in stagnation flow heat transfer with transpiration cooling. A significant series of experiments on free jets of nitrogen and helium, closely related to the above studies, indicate that thermal diffusion effects are considerably more important in a laminar shear layer than in a turbulent shear layer [17H].

A recent survey and annotated bibliography on mass transfer includes many works on combined heat and mass transfer [1H]. The similarity of the heat transfer when a gas is injected through a heated porous wall in contact with a liquid to boiling heat transfer is re-examined [3H].

CHANGE OF PHASE

Supplementing the many experimental

programs investigating the various aspects of phase change are an increasing number of attempts to interpret these observations through appropriate models of the mechanisms.

Kato [39J] analyses critically the relationship between heat fluxes and nucleate boiling parameters on open surfaces obtained by various authors. Further pool boiling studies include a contribution involving a photographic investigation of three distinct regimes occurring on a horizontal surface, leading Gaertner [18J] to question the validity of any model based on a single mechanism; Turton's concept [75J] of geometrical similarity; use of a microthermocouple probe to measure temperature profiles within the superheated boundary layer above and adjacent to a horizontal surface in saturated nucleate boiling [50J]; Madejski's [47J] three-component heat flux (columns of bubbles, liquid molecular heat conduction, eddy convection) theory; a two-part study by Han and Griffith [27J, 28J] establishing criteria for bubble initiation, growth, and departure and the application to predict a heat flux-temperature difference relation in good agreement with experiment. Borishanskiy and Fokin [4J] use mean vapor film thickness to correlate heat transfer data in stable film boiling on vertical surfaces. Rauber [64J] considers subcooled boiling of water flowing upward in annuli; Lapin *et al.* consider boiling nitrogen and neon in narrow annuli [42J]. Sideman and Barsky [70J] treat the effect of turbulence on heat transfer between an evaporating volatile liquid in direct contact with an immiscible liquid medium. Griffin and Coughanowr [24J] apply three previously developed methods to evaporation from a flat surface into an infinite depth vapor phase. In a two-part experimental study, Bankoff and co-workers [60J, 79J] treat film boiling of nitrogen with suction on an electrically heated porous plate. Noting the limited use of temperature to distinguish the boundary between nucleate and film boiling, Styrikovich *et al.* [71J] use deposits from a saturated salt solution to illuminate the mechanism. Meyer and Reinhard [53J] offer improvements in the numerical technique for boiling analysis.

Kutateladze and colleagues [40J] liken heat transfer during nucleate boiling to that occurring to a fluid in the neighborhood of a stagnation point. A series of studies considers aspects of nucleate boiling for several substances: Drayer [12J] compares predictions of eleven correlations with experimental data for liquid hydrogen; Lyon *et al.* [46J] consider peak nucleation fluxes for liquid oxygen at accelerations less than standard; Bobrovich and Mamontova [3J] photograph the boiling mechanism at high heat fluxes for water and alcohol; Wayner and Kesten [80J] study suction nucleate boiling on a porous heat source; Markels and Durfee [51J] deal with electrical field effects yielding fluxes twice that of normal nucleate boiling.

Burnout or critical heat flux is considered in a variety of situations: Duke [13J] obtains correlations for once-through superheat at low flow with an exponential source: Hewitt *et al.* [30J] study the behavior of a climbing water film on the heated central rod of an annular test section; Alekseev and co-workers [1J] measure heat fluxes in annular channels heated from both sides; Malenkov [48J] considers aspects of the critical phenomena in bubbling and boiling processes.

The following describe boiling heat transfer under rather special circumstances. Gambill [19J] tests the power density increase possible using twisted, electrical, heating tapes for the subcooled swirl-flow boiling process. Critical heat fluxes fall between 93 and 122 per cent of the flat tape values. Beckman and Merte [2J] photograph the pool boiling process in distilled and degassed water from normal to 100 times normal acceleration. The effect of pulsed heating during liquid boiling is reported by Pavlov and Skripov [62J]. The association of noise with boiling is investigated by Schwartz and Siler [69J] for possible relations between rate of heat transfer and noise parameters Hughmark [35J] cites limitations on the assumption of a constant slip factor in predicting pressure drop during forced circulating boiling of water. Charwat [8J] couples the behavior of the laminar boundary layer (with blowing) to the kinetic evaporation-rate law of the surface material.

Evaporation studies include heat- and mass-transfer rates of organic liquids and water into still air [72J], the asymptotic concentration distribution of an involatile solute in an evaporating drop [20J], and the use of monolayers to suppress evaporation [10J, 41J]. Martin and Edwards [52J] correlate latent heats of evaporation and Parisse and Klosner [61J] treat the ablation process for a hollow sphere.

Investigations on bubbles include their mechanics and dynamics in tubes [5J, 6J], formation dynamics at liquid boiling point [63J], growth mechanics of collapse [16J, 58J], and growth and rise in nucleate pool boiling [26J, 77J].

Condensation experiments on surface phenomena show no film larger than a monomolecular thickness exists on the area between drops. Surface imperfections are considered to be most probable nucleation sites [76J]. Ruckenstein and Metiu [65J] consider two mechanisms by which dropwise condensation may occur: small undercooling is associated with a few active sites, large undercooling involves so many active sites that a continuous film forms, reaches critical thickness, and breaks into drops which grow, especially through coalescences. The latter mechanism is studied in detail. A series of investigations are concerned with condensation promoters [38J, 43J, 74J], surface characteristics [73J], and the effect of noncondensible gas concentration [68J]. Edwards and Doolittle [14J] note a 16–30 per cent increase in heat transfer rate over film condensation, using a thin Teflon film. Under the special conditions or system specified, condensation heat transfer is studied: a vibrating tube [29J], a porous horizontal tube with uniform suction velocity [17J], a vertical plate with transverse electrostatic field [78J], a cold cylinder rotating at variable speed in a steam atmosphere [33J], from a system of mixed vapors [15J], and on a variable acceleration field [9J].

Mouradian and Sunderland [55J, 56J] analyse the velocity and temperature distribution in a liquid film on a flat surface. Related change of phase investigations study supercooling of water [7J], rate of ice formation on a cylindrical pipe [45J], ice crystal growth from its vapor [25J], and the tension field created by a spherical nucleus [32J].

Two-phase flow heat transfer of gas–liquid mixtures [air–water, air–ethylene] is correlated by the same relationship. Hughmark [34J] applies an earlier method of estimating heat-transfer coefficients in horizontal, annular, gas–liquid flow to the vertical upward configuration (average deviation: 25 per cent compared to steam–water experimental data). Holman *et al.* [31J] use induction heating of stainless steel and lead spheres fluidized in water to verify results of earlier particle–fluid studies. Aspects of two-phase gas–liquid flows consider the mechanisms of formation and maintenance of the annular regime in horizontal pipes [66J], an analysis of the annular liquid film flow [11J], and a comprehensive experimental study of upward annular flow of the air–water system [21J]. A two-part study by Ishigai and co-workers [36J, 37J] measure component flows in vertical two-phase flow by a pressure fluctuation technique.

Zuber and Findlay [81J] derive a general expression for predicting average volumetric concentration in two-phase flow systems. The major types of instabilities which can alter a given two-phase flow pattern and stability criteria correlating these is presented by Ostrach and Koestel [59J]. Malewski [49J] also experiments with a falling liquid film to determine the influence of waves in the CO_2–H_2O system. Other two-phase flow works related to heat transfer considerations include an experimental method for the direct measure of wall friction [23J], experiments of the vertical flow of R-12 [67J] prediction of two-phase critical flow [44J], a model for predicting maximum flow rate of a single component, two-phase mixture [54J], and a consideration of the pressure gradients in the approach region to critical flow [57J]. Govier [22J] describes the developments leading to better understanding of vertical, two-phase flow in the R. S. Jane Memorial Award Lecture.

RADIATION

The number of thermal radiation studies continues to multiply rapidly. In general, one may differentiate between studies made on radiant heat transfer through absorbing materials (sometimes including one or more of the following effects: scattering, thermal conduction, and convection), and radiant heat transfer between solid surfaces through a transparent medium.

The error introduced by assuming local thermodynamic equilibrium when calculating radiation transport in an optically thin medium is found to be small [50K]. The possibility of introducing a potential in calculating the radiant heat flux through an absorbing gas is noted in reference [10K]. The emittance of a sphere of an isothermal gray gas is calculated [31K]. The radiant heat transfer through a layer of gray gas between two plates, one of which is black, is little affected by whether the other plate reflects either diffusely or specularly [8K]. An approximation of the radiative transport between two non-opaque walls is presented [19K]. An analysis [37K] studies the approximations introduced by assuming a particular angular distribution of radiation when calculating the radiation transfer in an absorbing medium.

The accuracy of existing methods for determining the heat transfer through a layer of radiating gas between two parallel plates is evaluated [20K]. Calculations for the heat transfer in a conducting and absorbing fluid are presented for slug flow between parallel plates [55K], for Couette flow [16K], and for plane Poiseuille flow [17K]. The dependence of radiant heat transfer on flow patterns in a furnace is noted [27K]. The significance of radiation absorption in turbulent flow in the entrance region of an annulus is examined [38K]. The effect of radiant absorption on liquid thermal conductivity measurements [42K] and on transient conduction in a semi-infinite medium [32K] are presented. A simplified method is derived for calculating the thermal radiation from solid-propellent rocket exhausts [15K]. Experimental results for the combined radiation and convection heat transfer to a gas and powder mixture at high temperatures compare favorably with analysis [7K].

The heat transfer through a conducting material which scatters and absorbs radiation (as does a porous body) has been analysed [54K]. The influence of scattering, including multiple scattering, on radiative transfer in a homogeneous medium [21K, 36K] and the effect of anisotropic scattering on radiant heat transfer [35K] are studied. The radiant transfer from a cylindrical source in an infinite slab of non-absorbing anisotropic scattering material is calculated [9K]. An analysis [13K] considers the reflection and transmission of radiation falling obliquely on an absorbing, anisotropically scattering material.

Several studies are concerned with the effects of radiation heat transfer from shock layers. Including radiation absorption in a shock layer strongly affects the calculation of the inviscid flow and temperature distribution [51K]. The radiation from a plane shock layer in an infinite gray gas, including viscous and thermal conduction effects, is also analysed [53K]. Another analysis [40K] demonstrates the perturbation due to radiation absorption and emission on the flow field for normal and oblique shocks. An integral method predicts the surface heat transfer with a viscous, radiating, but non-absorbing shock layer [25K]. The shock layer with radiation emission, but no absorption, on a blunt ablating body is calculated (26K]. Radiation from a one-dimensional unsteady shock is found to affect the density and temperature fields, but has little effect on the pressure and velocity fields [56K]. Experiments on the radiative heating of cones in a hypersonic flow indicate an increase in heat transfer if an ablating material is used due to the radiation from the heated products of ablation [11K].

A review of the radiation properties of solid surfaces, including reciprocity relations, is presented [39K]. In calculating the radiation emitted from a solid surface, the index of refraction of the contiguous transparent medium must be considered [14K]. Analyses are presented on using an integrating sphere for studying either diffuse or specular solid surfaces [23K] or an absorbing scattering medium [43K]. Reciprocity relations show the effect of a non-diffuse surface in an integrating sphere [24K].

Approximations have been developed for calculating radiant heat transfer between the walls of an enclosure whose surfaces have directionally dependent radiation properties [4K] and whose surfaces are diffuse [47K]. The effect of polarization on reflection and absorption properties of a solid surface is examined [12K]. Shape factors are available for the radiation interchange between two spheres [28K] and between parallel finite and infinitely long cylindrical surfaces [44K]. Spectral emittance data is used to calculate the net heat transfer between parallel plates of polished refractory metals [6K]. Other calculations appear on radiation fins with convection [3K] and on radiation transfer between two concentric cylinders, the inner one having a number of perforations [49K].

Experiments [30K] on the emittance of cavities with diffuse walls tend to confirm analytical predictions. Recent analyses on the radiant transfer to and from cavities [29K, 33K], particularly cylindrical and conical ones, include temperature variations along the cavity wall [46K]. As the cavity surface is varied from completely diffuse to completely specular, the effective emittance of the cavity increases [34K, 48K]. A Monte Carlo technique calculates the directional reflectance and emittance of right circular cones with diffuse surfaces [41K].

Measurements of the reflection of a monochromatic pencil of radiation from a metal surface indicate that the surface effectively changes from diffuse to specular as the ratio of the wave length to surface roughness increases [5K]. Similar effects occur with electric nonconductors [52K]. The index of refraction and absorption coefficient of thin gold films are found to be independent of the direction of incident radiation [18K]. The emissivity of anisotropic materials (as exemplified by pyrolytic graphite) is strongly dependent on the crystal orientation [1K]. Measurements [45K] of the emissivities of iron, nickel, and platinum agree well with theoretical predictions. The infrared reflectances of evaporated films of silver and gold are found [2K] to be higher than previously reported values. The ratio of absorptance to emittance of selectively absorbing surfaces has been calculated [22K].

LIQUID METALS

The addition of controlled amounts of oxygen to turbulent flow of liquid sodium in a tube is shown to cause an increase in the thermal contact resistance between the fluid and the wall [3L]. Experimentally determined laminar Nusselt numbers lower than the theoretical limit (48/11 for flow in a uniformly heated tube) may be caused by the unwarranted use of a bulk temperature inferred from a straight line between the measured inlet and exit values [6L]. Additional heat-transfer data have been collected for sodium and mercury in logitudinal flow through a rod bundle [2L, 9L] and for NaK flowing in a circular tube with uniform wall heat flux [10L].

Predictions of turbulent heat transfer are made for liquid metal flows in annuli and in parallel plate channels for various heating conditions at the two bounding walls [5L, 4L]. An inviscid flow model is employed in analysing the liquid metal heat transfer from spheres and elliptic rods [7L].

Tests performed at one-g and zero-g with mercury vapor flowing and condensing in a horizontal circular tube show significant departures from the Lockhart–Martinelli two-phase flow pressure drop correlation, especially at low qualities [1L]. Another study using mercury at ordinary gravity leads to a similar conclusion [8L].

LOW-DENSITY HEAT TRANSFER

An excellent overview of the mechanics of highly rarefied gases is given by Patterson [7M] in the form of the 28th Wright Brothers Lecture. The unified panorama is outlined as well as the procedure to be followed for solving problems in the field. Theoretical studies occur through the work of Vallander [17M] who seeks a probabilistic description of the random processes in rarefied gas motion, and Grad's [3M] proof that for a general form of linear Boltzmann equation, with appropriate boundary conditions, all solutions approach equilibrium. Su [14M] considers linearized near-free molecule Couette flow in an attempt to explain the non-analytic nature of the correction term to macroscopic velocity.

A series of studies considers heat conduction under rarefied conditions for enclosures of various geometry. Springer and Tsai [12M] consider a monatomic or diatomic gas at rest between two concentric spheres and compare three methods (temperature-jump, free molecule, and mean-free-path) for calculating conduction heat transfer. Springer and Ratonyi [11M] work with concentric cylinders, calculating conduction heat transfer by extending the method of Lees and Liu to include the case where incomplete thermal accommodation exists at surface of inner cylinder. Willis [19M] considers heat transfer (and shear) between coaxial cylinders for large Knudsen numbers.

Lees [5M] re-examines von Kármán's contention that temperature jump arises naturally from the two-sidedness of the velocity distribution function, as he seeks a kinetic theory description of rarefied gas flow. Stupochenko's [13M] concern is also with temperature jump as he considers this effect in polyatomic gases. Sone [10M] discusses the response of a rarefied gas to an abrupt change of temperature of the bonding wall. Numerical values of the temperature jump are obtained.

Accommodation coefficients continue to attract the attention of various investigators. Morrison and Tuzi [6M] describe a new method used to obtain translational thermal accomodation coefficients for various vapors at a glass surface. Wachman [18M] outlines a procedure for determining accommodation coefficients from data in the temperature-jump range without applying temperature-jump theory. The effect of absorbed particles at a gas solid interface is found by Shin [9M] to have a significant influence on the accommodation coefficient for surface coverage as low as one per cent. Trichet and Gosse [16M] report numerical values of the coefficient for several gases on a clean metal wire.

Fried and Atkins [2M] report the results of a primarily experimental study of the interface thermal contact conductance between metals in a vacuum. A new model for predicting thermal contact resistance in a vacuum environment is proposed by Clausing and Chao [1M]. Macroscopic constriction is reported to have a commanding influence for surfaces and materials encountered in engineering practice.

Robertson [8M] extends results of previous studies (rectangular and circular orifices, circular ducts with perfect accommodation) to flow through circular ducts with arbitrary thermal accommodation coefficients. Ivanov [4M] reports density measurements near the forward critical point of a blunt body in supersonic rarefied gas flow. Taylor [15M] gives the correct velocity calculating heat transfer from single spheres in a low Reynolds number slip flow

MEASUREMENT TECHNIQUES

The number of published papers related to measurement techniques and instrumentation appears to be increasing rapidly. We shall consider only articles which deal specifically with temperature and heat-transfer measurements, novel techniques for measuring thermal conductivity, and flow measurement techniques having wide application in heat-transfer studies.

The effect of immersion depth of the reference thermocouple junction in an ice bath [8N] and a new design for an ice bath [15N] are described. New designs include a simple thermocouple compensator [6N] and a new apparatus for producing the triple point of water [12N]. The effects of electrochemical e.m.f.s when a thermocouple is in an electrolyte can be a significant part of the thermocouple e.m.f. [36N]. Another study [57N] predicts the effect of a thermocouple on the temperature of the medium in which it is immersed.

A preferentially wetted thermocouple measures the temperature of organic drops flowing in a continuous aqueous medium [28N]. Noble metal thermocouples have been used to measure temperature profiles through solid-propellant flames [43N]. At high temperature, noble metal thermocouples can be contaminated by their ceramic protection tubes [53N] even when in a vacuum. The instability of refractory metal thermocouples at high temperature has also been described [52N]. The use of Pt–Pt(Rh) thermocouples with non-catalytic coatings [10N] and their stability when welded to nickel surfaces [22N] are reported.

The results of long term use of platinum resistance thermometers at low temperature has been presented [49N]. A simplified equation can be used to calculate temperatures of platinum resistance thermometers [21N]. The transient response of resistance thermometers to a step function change in gas temperature is calculated [40N]. A bridge measures small temperature differences between two resistance thermometers [13N]. Transistor diodes and triodes [16N] and thermistor elements [5N] appear useful as temperature sensors. Parts for a NBS high precision gas thermometer have been described [1N]. Temperature sensitive surface coatings measure local surface temperatures in aerodynamic studies [25N, 26N].

Techniques for high temperature gas measurements [20N] include a probe containing two sensing elements with different heat capacities [18N]. Studies of optical pyrometry emphasize measurement of surface temperature [29N] and temperature during combustion in supersonic streams [33N]. Photographic pyrometry is used to measure the temperature of aerodynamically heated ceramic models [56N] and other surfaces to temperatures of 2255°K [14N]. Pyrometric techniques with monochromatic measurements, are used to measure target temperature in a solar furnace [27N], flame temperature [3N], and shock-tube gas temperature [31N].

Interferometric and schlieren techniques for low density studies are compared [35N]. A simplified interferometer constructed with relatively few large optical components is described [19N]. A grating interferometer using a laser light source has been built [48N]. In a schlieren interferometer, two parts (one passing through an undisturbed region) of the single beam of a schlieren system interfere with each other to give a fringe pattern similar to that of a Mach–Zehnder interferometer. Such units have recently been described and used to measure simple density (or temperature) distributions [7N, 34N, 41N]. A schlieren system can predict the temperature distribution in a laminar boundary layer [42N].

A calibration system for thin film resistance thermometers used in a shock tube has been described [46N]. A general study [2N] describes devices to measure surface heat flux. A heat flux meter utilizing a ceramic disc plated on both faces with thin film thermometers serves as a heat-flux meter (23N]. An instrument for measuring stagnation point heat transfer is described in reference [11N].

A simple radial heat flow apparatus measures thermal conductivities of gases and liquids [50N], while a dielectrically heated unit measures the thermal conductivity of a gas [51N]. Transient methods are employed to measure the thermal conductivity of liquids [4N] and the thermal diffusivity of solids [9N].

The advantages and limitations of the hydrogen bubble technique for quantitative studies of time dependent velocity fields in water are described [45N]. A hot wire anemometer measures low speed liquid mercury flows [44N]. A brief description of a laser flowmeter based on the Fizeau effect is cited in reference [30N]. By measuring the passage of the image of a particle across an optical grating, measurements of low fluid velocities can be made [17N]. The possible use of a thermistor anemometer is explored [37N]. The accuracy of a bubble meter (in which the time for a soap film to traverse a known volume is measured) in gas flow measurements is described [32N]. Ammonia, admitted through pressure taps, is used for flow visualization with a rotating surface [24N].

Preston tubes, for wall shear stress measurement, are calibrated for use at supersonic flows [47N] and in systems with pressure gradients [38N]. Wall shear stress is inferred from interferometric measurements of the evaporation rate of a thin liquid film on a highly polished surface [55N]. A highly sensitive manometer is constructed using optical interference to measure the difference in height of the two fluid columns of the unit [39N]. An accurate null-type pressure transducer is used up to pressures of 250 atm [54N].

HEAT-TRANSFER APPLICATIONS

Heat exchangers

A number of studies have appeared on general heat exchanger design and comparative performance of heat exchangers [1P, 13P, 18P, 22P, 23P]. An analysis has been made on a unit in which three different fluids exchange heat [14P]. Calculations of the exergy loss in heat exchangers have been extended to include the effects of a finite temperature difference [6P] and of mixing [5P]. The choice of a reference length to be used in heat exchanger calculations has been studied [17P]. The mean temperature difference in cross-flow heat exchangers with one or two passes has been calculated [10P]. The characteristics of heat exchangers made of closely packed Teflon tubes [4P] and skewed passages of glass–ceramic material [11P] have been described. The performance of a Hampson heat exchanger in which pairs of tubes are soldered together along their entire length has been analysed [12P].

Experiments on the transient response of a single-pass shell and tube heat exchanger agree well with an analysis of a distributed-parameter model heat exchanger [3P]. Another study [20P] indicates that a simplified one-pass model adequately predicts the dynamic behavior of a multipass heat exchanger. An analogue computer has been used to study heat-exchanger dynamics [7P].

Heat transfer in a vessel in which a fluid is agitated by a rotating impeller is correlated using a Reynolds number based on the impeller tip speed. Studies include heat transfer to the walls of the vessel [2P] and to a coil immersed in the vessel [19P]. The propeller pitch is found to have only a slight effect on the heat transfer [21P]. The dynamic response of such a system has also been studied [24P].

To transfer heat between two immiscible liquids, the two liquids can be put in direct contact by allowing them to flow through one another and then separating them by gravitimetric or other means. Heat exchangers of this type are being studied quite extensively for use in chemical industries. Due to the intimate contact between the two fluids, the heat exchange is highly effective [8P, 15P, 16P]. A countercurrent heat exchanger in which a vaporizing immiscible fluid is added to increase the heat transfer has also been studied [9P].

Aircraft and space vehicles

Experimental investigations determining the thermal conductivity of honeycomb-core panels [21Q] and of convective heat transfer to maneuvering surfaces [12Q] and to fins [6Q] provide the basis for an effective design of aircraft and spacecraft. The ablation process is still under extensive study including plastics [10Q], metallic bodies [16Q], and charring ablative materials [13Q]. Radiation is found to be the major source of heat transfer for spacecraft entering the atmosphere of Mars [8Q], and aerodynamic breaking is found attractive for the entry process compared with retro-rockets. Studies of heat transfer to meteors are conducted [1Q, 17Q] with the consideration that the understanding of these processes will also be helpful for the development of thermal protection systems for spacecraft.

An understanding of heat-transfer processes is essential for the development of rockets. Correspondingly, processes like heat conduction in star perforated solid propellant grains [26Q], transpiration cooling of nozzles [11Q], erosion of graphite by ablation [15Q], and convective heat transfer in nuclear rockets [22Q] have found attention. Heat transfer to the base areas of clustered rocket nozzles caused difficulties especially under choked conditions. Experiments therefore determined the value of the heat-transfer coefficients and their local distribution [25Q]. A simplified method to calculate thermal radiation emitted by solid particle clouds is applied to an analysis of thermal radiation from solid rocket plumes at high altitude [5Q].

Increasing attention is paid to radiative heat transfer in spacecraft. This includes analyses of fin and tube space radiators [7Q, 18Q], of the radiation properties of various surfaces [19Q, 20Q], and of methods to calculate radiative heat exchange to involved geometries under the condition of space flight [2Q, 4Q, 9Q, 24Q]. Similarity criteria for thermal modeling of spacecraft have been discussed [3Q].

Engines for supersonic aircraft have to operate at the highest possible temperature level. This makes the cooling of gas turbine blades interesting. Two papers report on investigations of forced convection liquid cooling [14Q] and on the influence of secondary flow on heat transfer to gas turbine blades [23Q].

THERMODYNAMIC AND TRANSPORT PROPERTIES

Thermodynamic properties

Critical point behavior receives wide interest. Baehr and Thurmer [7R] consider a water equation of state in the critical and supercritical region; Bridgeman and Aldrich [17R] reappraise the critical constants for the same substance; and Amirkhanov *et al.* [4R] investigate the heat capacity of heavy water in this region. Critical state behavior of helium (He^3) is observed by Sherman [117R] and an equation of state for He^4 constructed by Tisza and Chase [122R]. Voronel' *et al.* [127R] consider heat capacity (C_v) singularities at the critical point and Botch and Fixman [14R] predict critical region heat capacities using approximations similar to those applied to binary mixtures. Thodos and co-workers report critical temperature and pressure for the ethane–*n*-heptane system [38R] and the ethane–*n*-pentane–*n*-heptane system [32R].

Continued interest in the corresponding states theorem extends from liquid to gas including the boundary between these phases. Kuloor and co-workers [126R] examine the utility of various theories, and present verification of the theorem using entropy data for twenty gases [99R]. The choice of reference point for studying thermodynamic similarity of gases concerns Kasavchinskii [58R], while Reid and Leland [103R] provide rules to determine the reduced properties for mixtures in order that pure component generalizations may be used in estimating mixture properties. Narsimhan [87R] generalized saturated liquid density with temperature at various critical compressibility factors. The theorem is used by Malyshev [74R] to correlate vapor pressure information, to predict binary system vapor–liquid equilibrium, Nagata [85R], and by several workers [26R, 88R, 92R] to generalize latent heats of vaporization. Nagata [86R] also measures vapor–liquid equilibrium data for three binary systems. The Canfield–Kobayashi group report compressibility factors for helium–nitrogen mixtures [24R], and compile the full range of thermodynamic properties for the helium nitrogen system [94R]. Henderson [51R] reviews progress over the last few years in liquids and Eyring *et al.* [101R] present the reduced thermodynamic functions for the significant structure theory of simple liquids. Excess thermodynamic functions for the liquid mixture methane–propane are given by Cutler and Morrison [31R]. Rao [100R] uses the rigid sphere model to evaluate one of the parameters connecting the surface tension and liquid compressibility. Other mixture works examine the excess thermodynamic properties of twenty-three equimolar binary liquid systems of small non-polar molecules [1R] and the departures from Dalton's and Amagat's laws by oxygen carbon dioxide and oxygen–nitrous oxide systems [35R].

Guggenheim [45R] considers variations of the van der Waal's equation of state for high densities. Kielich [62R] treats the equation of state for gas mixtures comprising unlike polar molecules. Useful property data for refrigerants is given for R-114 by Morsy [83R], R-216 by Shank [115R], R-113 by Higgins and Lielmezs [53R], and for isopentane [6R]. The properties of partially ionized *hydrogen* is reported by Fauchais and Manson [41R]. Other works estimate heat capacities of organic compounds from group contributions [104R], calculate zero pressure specific heats for fluorine–chlorine derivatives of methane [11R], and present Joule–Thomson curves for nine substances [121R].

Theoretical interest in intermolecular potentials is shown by Hecht [49R] in his virial development for molecules undergoing pure repulsion, by Wilson's consideration [129R] of the London potential between rare gas atom pairs, and by Rossi and Danon [107R] who describe the superiority of the Kihara potential. Virial coefficient data is presented for nonpolar, nonspherical molecules [110R], for propyne based on the Stockmayer potential [15R], for squares and cubes with attractive forces [54R], and for a two-dimensional Lennard-Jones gas [109R]. Ben-Naim [12R] comments on the difference of thermodynamic behavior of argon in ordinary and heavy water. Hamel [47R] presents a kinetic model for binary gas mixtures, and Menon [79R] calculates interaction second virial coefficients for 20 binary gas mixtures. For solids, Leadbetter [67R] calculates properties for ordinary and heavy ice. Dixon *et al.* [36R] the low temperature heat capacities of seven pure metals, and du Chatenier *et al.* [37R] the heat capacity of stainless steel in the temperature range 1·3–30°K. Kestin [60R] and Haywood [48R] report on the Sixth International Conference on the Properties of Steam.

Transport properties

Brokaw [18R] presents a very useful summary of recent advances in dilute gas transport properties. Eyring [106R] and co-workers apply their significant structure theory to liquids and find close agreement with Enskog theory for rigid spheres. Investigations of various molecular models include the square-well potential [20R], Kihara's potential [108R], exponential attractive potential [84R], 9-6 and 28-7 potentials [119R], and rough spheres [28R]. Transport properties are considered under the special conditions of high density [30R, 39R, 70R], high temperatures [42R, 59R], and gases with rotational states [78R]. Specific calculations have been made for hydrogen [16R, 21R], helium [81R], krypton [8R], hydrocarbon vapors in the methane series [90R], and alkali metal vapors [33R]. The accuracy of empirical mixture formulas for thermal conductivity and viscosity is analysed by Burnett [22R] and Brokaw [19R]. Simon *et al.* [118R] report properties for mixtures of hydrogen with nitrogen and with carbon-dioxide.

Experimental measurements of diffusion coefficients using the diaphragm-cell are reported by Robinson *et al.* [105R].* Thermal

* Stefan diffusion tube results are examined carefully by Heinzelman *et al* [50R].

diffusion factor results obtained by the swing-separator (*trennschaukel*) method are given for xenon [93R]. Various methods for measuring this property are reviewed by Joshi and Saxena [56R]. Other works concerned with mass transport effects are: interrelation of thermal diffusion in binary gas mixtures and intermolecular forces [112R], thermal diffusion and transfer of rotational energy [34R]. gas diffusion and ideal critical volume [125R], energy associated with gas diffusion [75R], and a correction to a relation for the thermal diffusion coefficient [64R].

Gandhi and Saxena [43R] show the suitability of five different methods of the Wassiljewa form for calculating the translational thermal conductivity of gas mixtures at high temperatures. Sengers [113R] presents additional information to confirm the existence of a maximum thermal conductivity in the critical region. Experimental measurements of thermal conductivity by various methods are reported for the following substances: Argon and nitrogen, 140–348°C [61R]; liquid and gaseous ammonia, 20–177°C [91R]; argon, 20000–75000°K [23R]; helium, 1600–6700°K [27R]; hydrogen, 90–280°K [116R]; nitrogen, 22·2, 50·5°C [80R]; some polymers, 1–4·5°K [102R]; sulphur dioxide, 295–887°K [9R].

A general prediction scheme useful to 10000°K, is presented by Mathur and Thodos [77R]. Other theoretical studies for gases are concerned with: high temperature nitrogen thermal conductivity [123R], partially and fully ionized gas thermal conductivity [2R], non-polar polyatomic gas mixture conductivity [111R], polar polyatomic gas mixture conductivity [82R], and aspects of H_2O–D_2O mixture conductivity [120R].

Liquid thermal conductivity measurements are reported by Venart [124R], Poltz (six fluids) [96R], and Vodar and co-workers [69R], the latter about the critical state. Mallon and Cutler [73R] measure the thermal conductivity for electrically conducting liquids.

Experimental measurements of the thermal conductivity for various solids are reported: high purity iron, 7–200°K [5R]; nickel [98R]; sodium, 90–850°C [40R]; new and used fireclay, magnesite, chrome magnesite, and forsterite brick [55R]; various solid materials, 200–1000°C [10R]. Other studies in this area deal with the anisotropy of thermal conductance in near-ideal graphite [52R], effect of cold work on copper thermal conductivity [128R], and electronic thermal conductivity in solids [71R]. A useful correlation between metallic thermal and electrical conductivities is given by Powell [97R], and the law of corresponding states applied to metals by Cezairliyan and Touloukian [25R].

Experimental viscosity measurements by the capillary method are reported by Cronin [29R] for air, N_2, CO_2, Ar, He, H_2, accurate from 2 to 3 per cent; for methane the rotating cylinder is used [95R]. Data is also reported for *n*-pentane [68R], steam and water [13R, 66R], liquid sodium and potassium [44R], liquid and vapor refrigerants [130R], and mineral oils [65R].

Theoretical calculations exhibit a concern with density effects. Sengers [114R] investigates the first density correction for a two-dimensional rigid sphere gas. Kim and Ross [63R] consider the influence of triple collisions on dense gas viscosity. Das Gupta and Barus [46R] calculate ammonia viscosity at elevated pressures according to dimerization postulate. Methyl chloride and methane viscosities are calculated by Aksaraillian and Cerceau [3R].

Mallikarjun and Hill [72R] consider the temperature dependence of viscosity in simple polar liquids. Saxena and co-workers extend the Kihar method to determine the second approximation of binary gas mixture viscosities [57R] and use a Sutherland expression for predicting multi-component viscosities of mixtures involving polar gases [76R].

REFERENCES

Books

1. W. F. AMES (editor), *Nonlinear Problems of Engineering*. Academic Press, New York (1964).

2. J. W. Bond Jr., K. M. Watson and J. A. Welch Jr., *Atomic Theory of Gas Dynamics*. Addison-Wesley, Reading, Mass. (1965)
3. V. M. Borishanskii (editor), *Liquid Metals*. Collection of Articles. AEC-TR-6554, Division of Technical Information, Atomic Energy Commission, Washington. D.C. (1965).
4. A. F. Charwat (editor), *Proceedings of the 1965 Heat Transfer and Fluid Mechanics Institute*. Stanford University Press, Stanford, Calif. (1965).
5. J. Coull and E. B. Stuart, *Equilibrium Thermodynamics*. John Wiley, New York (1964)
6. D. A. Gilbrech, *Fluid Mechanics*. Wadsworth, Belmont, Calif. (1965).
7. I. Granet, *Elementary Applied Thermodynamics*. John Wiley, New York (1965).
8. J. P. Hartnett and T. F. Irvine Jr., *Advances in Heat Transfer*, Vol. 2. Academic Press, New York (1965).
9. P. G. Hill and C. R. Peterson, *Mechanics and Thermodynamics of Propulsion*. Addison-Wesley, Reading, Mass. (1965).
10. W. Kays and A. L. London, *Compact Heat Exchangers*, 2nd edn. McGraw-Hill, New York (1964).
11. S. Katzoff (editor), *Symposium on Thermal Radiation of Solids*. NASA SP-55 (1965).
12. A. D. Kraus, *Cooling Electronic Equipment*. Prentice-Hall, Englewood Cliffs, N.J. (1965).
13. F. Kreith, *Principles of Heat Transfer*, 2nd edn. International Textbook, Scranton, Pa. (1965).
14. S. Ostrach and R. H. Scanlan, *Developments in Mechanics*. Pergamon Press, Oxford (1965).
15. E. L. Phillips (chairman), *Symposium on Air-Cooled Heat Exchangers*, 7th National Heat Transfer Conference, Cleveland, Ohio (1964).
16. W. M. Rohsenow (editor). *Developments in Heat Transfer*. Edward Arnold, London (1964).
17. R. M. Scroggins (editor), *Proceedings of the Second Joint USAEC-EURATOM Two-Phase Flow Meeting*. CONF-640507, Division of Reactor Development. Atomic Energy Commission, Washington. D.C. (1964).

Conduction

1A. L. V. Beliakov, V. P. Valitskii and N. A. Zlatin, *Dokl. Akad. Nauk SSSR* **160**, 314 (1965).
2A. K. B. Bischoff, *Chem. Engng Sci.* **20**, 783 (1965).
3A. J. R. Bowey, *Chem. Engng Sci.* **20**, 712 (1965).
4A. J. J. Brogan, *J. Spacecraft Rockets* **2**, 112 (1965).
5A. P. E. Bulavin and V. M. Kashcheev, *Int. Chem. Engng* **5**, 112 (1965).
6A. T. R. Bump, *J. Heat Transfer* **87**, 526 (1965).
7A. B. T. Chao, *J. Heat Transfer* **87**, 349 (1965).
8A. S. W. Churchill, *A.I.Ch.E. Jl* **11**, 431 (1965).
9A. A. F. Emery, *AIAA Jl* **3**, 1525 (1965).
10A. B. Gay, *Int. J. Heat Mass Transfer* **8**, 507 (1965).
11A. A. C. Giere, *Appl. Scient. Res.* **A14**, 191 (1964–65).
12A. J. R. Griffin and D. R. Coughanowr, *A.I.Ch.E. Jl* **11**, 133 (1965).
13A. K. W. Haley and J. W. Westwater, *Chem. Engng Sci.* **20**, 711 (1965).
14A. H. Halle, *J. Heat Transfer* **87**, 420 (1965).
15A. J. H. Heasley, *Int. J. Heat Mass Transfer* **8**, 14 (1965).
16A. G. Horvay, *J. Heat Transfer* **87**, 1 (1965).
17A. F. Jackson, *J. Heat Transfer* **87**, 329 (1965)
18A. R. A. Jones and J. L. Hunt, *J. Spacecraft Rockets* **2** 632 (1965).
19A. D. D. Joseph, *Int. J. Heat Mass Transfer* **8**, 281 (1965)
20A. J. T. Lardner, *J. Heat Transfer* **87**, 423 (1965).
21A. P. A. Laura and M. Chi, *Aeronaut. Q.* **16**, 221 (1965).
22A. N. N. Lebedev and I. P. Skal'skaya, *Soviet Phys. Tech. Phys.* **9**, 1207 (1965).
23A. B. D. Lee and P. D. Richardson, *J. Mech. Engng Sci.* **7**, 127 (1965).
24A. P. A. Libby and S. Chen, *Int. J. Heat Mass Transfer* **8**, 395 (1965).
25A. U. S. Lindholm, E. J. Baker and R. C. Kirkpatrick, *J. Heat Transfer* **87**, 49 (1965).
26A. F. F. Ling and V. C. Mow, *J. Bas. Engng* **87**, 729 (1965).
27A. A. V. Masket, *Am. J. Phys.* **33**, 196 (1965).
28A. M. D. Mikhailov, *J. Appl. Mech. Tech. Phys.* No. 6, 305 (1965).
29A. A. R. Mitchell and G. Fairweather, *Num. Math* **6**, 285 (1964).
30A. H. F. Mueller and N. D. Malmuth, *Int. J. Heat Mass Transfer* **8**, 915 (1965)
31A. N. G. O'Brien and R. L. Turner, *A.I.Ch.E. Jl* **11**, 546 (1965).
32A. I. U. Ojalvo and F. D. Linzer, *Q. Jl Mech. Appl Math.* **18**, 41 (1965).
33A. N. Y. Ölçer, *Int. J. Heat Mass Transfer* **8**, 529 (1965)
34A. R. Palinski, *Nukleonik* 7, 93 (1965).
35A. B. A. Peavy, *J. Res. Natn. Bur. Stand.* **69C**, 145 (1965).
36A. J. E. Phythian, *AIAA Jl* **3**, 151 (1965)
37A. A. W. Pratt, *Int. J. Heat Mass Transfer* **8**, 861 (1965)
38A. B. C. Raychaudhuri, *Int. J. Heat Mass Transfer* **8** 1439 (1965).
39A. C. N. Rollinger, *J. Heat Transfer* **87**, 259 (1965)
40A. G. C. Sih, *J. Heat Transfer* **87**, 293 (1965).
41A. D. C. Stickler, *Appl. Scient. Res.* **A14**, 279 (1964–65).
42A. D. W. Stops, *J. Scient. Instrum.* **42**, 263 (1965)
43A. G. Strassacker, *Z. Ver. Dt. Ing.* **107**, 1180 (1965)
44A. S. Sugiyama, T. Kato, M. Nakamura and M. Kito, *J. Chem. Soc. Japan* **68**, 94 (1965)
45A. L. A. Svergunenko, *Dopov. Akad. Nauk URSR* No. 4, 460 (1965).
46A. L. C. Tien and S. W. Churchill, *A.I.Ch.E. Jl* **11**, 790 (1965).
47A. T. Todoroff, *Kältetechnik* **17**, 238 (1965)
48A. R. Thorsen and F. Landis, *Int. J. Heat Mass Transfer* **8**, 189 (1965).
49A. V. Vodicka, *Appl. Scient. Res.* **A14**, 301 (1964–65)
50A. I. M. Winer, *Q. Appl. Math.* **23**, 82 (1965)
51A. T. A. Zaker, *J. Appl. Mech.* **32**, 143 (1965)
52A. R. O. Zermuehlen and H. L. Harrison, *ASHRAE Jl* 7, 25 (1965).
53A. R. D. Zerkle and J. E. Sunderland, *J. Heat Transfer* **87**, 117 (1965).
54A. G. F. Zinsmeister and J. R. Dixon, *Int. J. Heat Mass Transfer* **8**, 1 (1965)

Channel Flow

1B. M. AL-ARABI, *Appl. Scient. Res.* **A14**, 321 (1964–65).
2B. P. J. BAKER, *J. Mech. Engng Sci.* **7**, 1 (1965).
3B. A. E. BERGLES and P. H. NEWELL JR., *Int. J. Heat Mass Transfer* **8**, 1273 (1965).
4B. D. BRADLEY and A. G. ENTWISTLE, *Int. J. Heat Mass Transfer* **8**, 621 (1965).
5B. K. C. CHENG, *J. Heat Transfer* **87**, 308 (1965).
6B. S. C. CHU and S. G. BANKOFF, *Appl. Scient. Res.* **A14**, 379 (1964–65).
7B. S. C. CHU and S. G. BANKOFF, *A.I.Ch.E. Jl* **11**, 607 (1965).
8B. C. COWHERD JR. and H. E. HOELSCHER *I/EC Fundamentals* **4**, 150 (1965).
9B. M. E. DAVENPORT and G. LEPPERT, *J. Heat Transfer* **87**, 191 (1965).
10B. M. E. ERDOGAN, *Z. Angew. Math. Phys.* **16**, 542 (1965).
11B. Z. T. GALIULLIN and E. L. KRIVOSHEIN, *Int. Chem. Engng* **5**, 341 (1965).
12B. J. E. GERRARD, F. E. STEIDLER and J. K. APPLEDOORN, *I/EC Fundamentals* **4**, 332 (1965).
13B. U. GRIGULL and H. TRATZ, *Int. J. Heat Mass Transfer* **8**, 669 (1965).
14B. N. HAYASI and K. INOUYE, *J. Heat Transfer* **87**, 513 (1965).
15B. H. L. HESS and H. R. KUNZ, *J. Heat Transfer* **87**, 41 (1965).
16B. T. HOBLER and K. KOZIOL, *Int. Chem. Engng* **5**, 672 (1965).
17B. J. P. HOLMAN, S. N. REA and C. E. HOWARD, *Int. J. Heat Mass Transfer* **8**, 1095 (1965).
18B. C. J. HSU, *A.I.Ch.E. Jl* **11**, 938 (1965).
19B. C. J. HSU, *A.I.Ch.E. Jl* **11**, 690 (1965).
20B. J. L. HUDSON and S. G. BANKOFF, *Chem. Engng Sci.* **20**, 415 (1965).
21B. C. L. HWANG and L. T. FAN, *Appl. Scient. Res.* **A13**, 401 (1964).
22B. C. L. HWANG, P. J. KNIEPER and L. T. FAN, *Z. Angew. Math. Phys.* **16**, 599 (1965).
23B. R. M. INMAN, NASA TN D-2674 (1965).
24B. T. W. JACKSON and K. R. PURDY, *J. Heat Transfer* **87**, 507 (1965).
25B. D. D. JOSEPH, *Physics Fluids* **7**, 1761 (1964).
26B. M. K. KISHINEVSKY, *Int. J. Heat Mass Transfer* **8**, 1181 (1965).
27B. V. KOLAŘ, *Int. J. Heat Mass Transfer* **8**, 639 (1965).
28B. V. KUBAIR and N. R. KULOOR, *Indian J. Technol.* **3**, 5 (1965).
29B. V. KUBAIR and N. R. KULOOR, *Indian J. Technol.* **3**, 1 (1965).
30B. V. KUBAIR and N. R. KULOOR, *Indian J. Technol.* **3**, 144 (1965).
31B. V. KUBAIR and N. R. KULOOR, *Indian J. Technol.* **3**, 147 (1965).
32B. V. KUBAIR and N. R. KULOOR, *Indian J. Technol.* **3**, 173 (1965).
33B. R. KUMAR, *J. Phys. Soc. Japan* **20**, 1255 (1965).
34B. B. S. LARKIN, *J. Mech. Engng Sci.* **7**, 300 (1965).
35B. S. M. LEE and W. N. GILL, *A.I.Ch.E. Jl* **10**, 896 (1964).
36B. D. A. MCCARTHY and J. J. C. PICOT, *Can. J. Chem. Engng* **42**, 277 (1964).
37B. D. M. MCELIGOT, P. M. MAGEE and G. LEPPERT, *J. Heat Transfer* **87**, 67 (1965).
38B. S. P. MISHRA, *Appl. Scient. Res.* **A14**, 182 (1964–65).
39B. S. MATSUHISA and R. B. BIRD, *A.I.Ch.E. Jl* **11**, 588 (1965).
40B. Y. MORI and W. NAKAYAMA, *Int. J. Heat Mass Transfer* **8**, 67 (1965).
41B. J. L. NOVOTNY and E. R. G. ECKERT, *J. Heat Transfer* **87**, 313 (1965).
42B. R. J. NUNGE and W. N. GILL, *Int. J. Heat Mass Transfer* **8**, 873 (1965).
43B. Y. PENG and S. W. YUAN, *J. Heat Transfer* **87**, 252 (1965).
44B. H. C. PERKINS and P. WORSØE-SCHMIDT, *Int. J. Heat Mass Transfer* **8**, 1011 (1965).
45B. D. N. ROY, *J. Heat Transfer* **87**, 425 (1965).
46B. U. A. SASTRY, *Appl. Scient. Res.* **A13**, 269 (1964).
47B. U. A. SASTRY, *Indian J. Pure Appl. Phys.* **3**, 113 (1965).
48B. J. M. SAVINO and R. SIEGEL, NASA TN D-2860 (1965).
49B. S. SIDEMAN, D. LUSS and R. E. PECK, *Appl. Scient. Res.* **A14**, 157 (1964–65).
50B. R. SIEGEL and J. M. SAVINO, *J. Heat Transfer* **87**, 59 (1965).
51B. J. W. SMITH and R. A. GOWEN, *A.I.Ch.E. Jl* **11**, 941 (1965).
52B. W. T. SNYDER, *Appl. Scient. Res.* **A14**, 1 (1964–65).
53B. E. M. SPARROW and A. HAJI-SHEIKH, *J. Heat Transfer* **87**, 426 (1965).
54B. E. M. SPARROW and J. B. STARR, *J. Appl. Mech.* **32**, 684 (1965).
55B. MARY K. STRITE and R. M. INMAN, NASA TN D-3039 (1965).
56B. H. S. SWENSON, J. R. CARVER and C. R. KAKARALA, *J. Heat Transfer* **87**, 477 (1965).
57B. H. TAKAHAMA, *Bull. J.S.M.E.* **8**, 433 (1965).
58B. M. F. TAYLOR, NASA TN D-2595 (1965).
59B. C. TIEN and R. A. PAWELEK, *Appl. Scient. Res.* **A13**, 317 (1964).
60B. R. M. TURIAN, *Chem. Engng Sci.* **20**, 771 (1965).
61B. D. L. ULRICHSON and P. A. SCHMITZ, *I/EC Fundamentals* **4**, 2 (1965).
62B. D. L. ULRICHSON and R. A. SCHMITZ, *Int. J. Heat Mass Transfer* **8**, 253 (1965).
63B. P. M. WORSØE-SCHMIDT and G. LEPPERT, *Int. J. Heat Mass Transfer* **8**, 1281 (1965).
64B. W. J. YANG, *J. Appl. Mech.* **32**, 454 (1965).
65B. A. J. ZIEGENHAGEN, *Int. J. Heat Mass Transfer* **8**, 499 (1965).

Boundary-layer Flow

1C. A. ACRIVOS and J. D. GODDARD, *J. Fluid Mech.* **23**, 273 (1965).
2C. L. H. BACK and R. A. SEBAN, *J. Heat Transfer* **87**, 151 (1965).
3C. H. BEER, *Chemie-Ingr-Tech.* **37**, 1047 (1965).
4C. E. A. BROWN JR and P. A. ROSS *AIAA Jl* **3**, 660 (1965).
5C. A. R. BUYUKTUR and J. KESTIN, *J. Heat Transfer* **87**, 403 (1965).
6C. A. CASACCIO and S. COUSIN, *AIAA Jl* **3**, 756 (1965).
7C. B. T. CHAO and D. R. JENG, *J. Heat Transfer* **87**, 221 (1965).

8C. Z. H. Chaudhury, *J. Fluid Mech.* **20**, 501 (1964).
9C. R. Chand and H. F. Rosson, *I/EC Fundamentals* **4**, 356 (1965).
10C. D. L. Compton and D. M. Cooper, *AIAA Jl* **3**, 165 (1965).
11C. C. J. Cremers and E. R. G. Eckert, *AIAA Jl* **3**, 1876 (1965).
12C. A. M. Dhanak, *J. Heat Transfer* **87**, 231 (1965).
13C. E. J. Felderman and R. C. Fellinger, *AIAA Jl* **3**, 1207 (1965).
14C. J. Fillo, *AIAA Jl* **3**, 1339 (1965).
15C. N. C. Freeman and P. G. Simpkins, *Q. Jl Mech. Appl. Math.* **18**, 213 (1965).
16C. J. B. Heywood and W. C. Moffatt, *AIAA Jl* **3**, 1565 (1965).
17C. G. S. Janowitz and P. A. Libby, *Int. J. Heat Mass Transfer* **8**, 7 (1965).
18C. I. Kimura and A. Kanzawa, *AIAA Jl* **3**, 476 (1965).
19C. N. H. Kemp, *AIAA Jl* **2**, 1864 (1964).
20C. Yu. A. Koshmarov and N. M. Gorskaya, *Int. J. Heat Mass Transfer* **8**, 1415 (1965).
21C. N. G. Kulgein, *AIAA Jl* **3**, 230 (1965).
22C. P. A. Libby, *Int. J. Heat Mass Transfer* **8**, 1254 (1965).
23C. P. A. Libby and H. Fox, *Int. J. Heat Mass Transfer* **8**, 1451 (1965).
24C. K. H. Lillich, *Z. Ver. Dt. Ing.* **107**, 803 (1965).
25C. M. A. Lutz, *AIAA Jl* **3**, 772 (1965).
26C. F. A. Lyman, *Appl. Scient. Res.* **A13**, 65 (1964).
27C. J. G. Marvin and C. M. Akin, NASA TN D-3017 (1965).
28C. W. C. Meecham, *AIAA Jl* **3**, 1192 (1965).
29C. P. M. Moretti and W. M. Kays, *Int. J. Heat Mass Transfer* **8**, 1187 (1965).
30C. S. Ostrach and D. G. McConnell, *AIAA Jl* **3**, 1883 (1965).
31C. E. Pfender and E. R. G. Eckert, *Proceedings of the 1965 Heat Transfer and Fluid Mechanics Institute*. Stanford University Press, Stanford, Calif. (1965).
32C. P. Ramamoorthy, *Q. Jl Mech. Appl. Math.* **18**, 31 (1965).
33C. P. H. Rose and J. O. A. Stankevics, *AIAA Jl* **3**, 1623 (1965).
34C. G. N. Sarma, *Proc. Camb. Phil. Soc.* **61**, 809 (1965).
35C. K. S. Sastri, *Appl. Scient. Res.* **A14**, 126 (1964–65).
36C. K. S. Sastri, *J. Phys. Soc. Japan* **20**, 1711 (1965).
37C. J. Schenk, *Appl. Scient. Res.* **A13**, 339 (1964).
38C. J. A. Schetz and J. Jannone, *J. Heat Transfer* **87**, 157 (1965).
39C. E. U. Schlünder and D. Grohne, *Chemie-Ingr-Tech.* **37**, 811 (1965).
40C. W. H. Schwartz and M. O'Nan, *Chem. Engng Sci.* **20**, 365 (1965).
41C. P. G. Simpkins, *Int. J. Heat Mass Transfer* **8**, 99 (1965).
42C. A. M. O. Smith and D. W. Clutter, *AIAA Jl* **3**, 639 (1965).
43C. E. M. Sparrow and S. H. Lin, *Int. J. Heat Mass Transfer* **8**, 437 (1965).
44C. H. Tong, *AIAA Jl* **3**, 773 (1965).
45C. R. W. Truitt, *AIAA Jl* **3**, 1754 (1965).
46C. A. Walz, *Z. Flugwiss.* **13**, 89 (1965).
47C. A. H. Whitehead Jr. and J. C. Dunavant, NASA TN D-2708 (1965).
48C. R. E. Wilson, *J. Spacecraft Rockets* **2**, 490 (1965).
49C. A. D. Young, *Aeronaut. Q.* **15**, 392 (1964).

Flow with Separated Regions

1D. A. A. Austin, R. B. Beckmann, R. R. Rothfus and R. I. Kermode, *I/EC Process Des. Dev.* **4**, 379 (1965).
2D. J. J. Barker, *Ind. Engng Chem.* **57**, 42 (1965).
3D. J. J. Barker, *Ind. Engng Chem.* **57**, 33 (1965).
4D. K. H. Baumann, *Z. Ver. Dt. Ing.* **107**, 513 (1965).
5D. G. N. Bhat and E. Weingaertner, *Br. Chem. Engng* **10**, 615 (1965).
6D. V. A. Borodulya and A. I. Tamarin, *Int. Chem. Engng* **5**, 432 (1965).
7D. R. F. Cuffel and B. H. Sage, *Int. J. Heat Mass Transfer* **8**, 1085 (1965).
8D. C. F. Dewey Jr., *Int. J. Heat Mass Transfer* **8**, 245 (1965).
9D. A. G. Durmish'yan, Yu. G. Mamedov, A. Kh. Mirzadzhanzade, N. M. Rafibeili and E. S. Sadykh-Zade, *Int. Chem. Engng* **5**, 91 (1965).
10D. R. M. Fand, *Int. J. Heat Mass Transfer* **8**, 995 (1965).
11D. J. Fox, *Int. J. Heat Mass Transfer* **8**, 269 (1965).
12D. J. D. Gabor, B. E. Stangeland and W. J. Mecham, *A.I.Ch.E. Jl* **11**, 130 (1965).
13D. R. Gardon and J. C. Akfirat, *Int. J. Heat Mass Transfer* **8**, 1261 (1965).
14D. J. Gosse, *C.R. Hebd. Séanc. Acad. Sci., Paris* **258**, 5141 (1964).
15D. J. P. Holman, T. W. Moore and V. M. Wong, *I/EC Fundamentals* **4**, 21 (1965).
16D. F. M. Julian and A. E. Dukler, *A.I.Ch.E. Jl* **11**, 853 (1965).
17D. R. B. Keey and J. B. Glen, *Trans. Instn Chem. Engrs* **43**, 221 (1965).
18D. O. Krischer and E. Mosberger, *Chemie-Ingr-Tech.* **37**, 925 (1965).
19D. I. J. Kumar and H. N. Narang, *Int. J. Heat Mass Transfer* **8**, 567 (1965).
20D. V. S. Nosov and N. I. Syromiatnikov, *Dokl. Akad. Nauk SSSR* **163**, 624 (1965).
21D. K. Ofuchi and D. Kunii, *Int. J. Heat Mass Transfer* **8**, 749 (1965).
22D. A. L. Parnas, *Int. Chem. Engng* **5**, 213 (1965).
23D. P. D. Richardson, *AIAA Jl* **3**, 537 (1965).
24D. P. N. Rowe, K. T. Claxton and J. B. Lewis, *Trans. Instn Chem. Engrs* **43**, 14 (1965).
25D. R. A. Seban, *Int. J. Heat Mass Transfer* **8**, 1353 (1965).
26D. B. L. Siegel, W. L. Maag, J. B. Slaby and W. F. Mattson, NASA TN D-2924 (1965).
27D. B. Wasmund and J. W. Smith, *Can. J. Chem. Engng* **43**, 246 (1965).
28D. V. W. Weekman Jr. and J. E. Myers, *A.I.Ch.E. Jl* **11**, 13 (1965).
29D. F. N. Ziegler, R. W. Frischmuth Jr. and W. J. Brazelton, *I/EC Process Des. Dev.* **4**, 239 (1965).

Transfer Mechanisms

1E. J. Binckebanck, *Int. J. Heat Mass Transfer* **8**, 83 (1965).

2E. R. A. Burton, *AIAA Jl* **3**, 784 (1965).
3E. D. Coles, *J. Fluid Mech.* **21**, 385 (1965).
4E. R. G. Deissler, *Physics Fluids* **8**, 391 (1965).
5E. F. V. A. Engel, *Z. Ver. Dt. Ing.* **107**, 671 (1965).
6E. J. Fox, *Int. J. Heat Mass Transfer* **8**, 467 (1965).
7E. K. Lee and H. Barrow, *Int. J. Heat Mass Transfer* **8**, 403 (1965).
8E. D. G. Mabey, *Jl R. Aeronaut. Soc.* **69**, 96 (1965).
9E. G. Q. Martin and L. N. Johanson, *A.I.Ch.E. Jl* **11**, 29 (1965).
10E. H. S. Mickley, K. A. Smith and M. D. Fraser, *AIAA Jl* **3**, 787 (1965).
11E. R. J. Sanator, J. P. DeCarlo and D. T. Torrillo, *AIAA Jl* **3**, 758 (1965).
12E. R. C. Seagrave, *A.I.Ch.E. Jl* **11**, 748 (1965).
13E. S. P. Sutera, *J. Fluid Mech.* **21**, 513 (1965).
14E. R. S. Tyul'panov, *Int. Chem. Engng* **5**, 77 (1965).
15E. E. R. van Driest, *Int. J. Engng Sci.* **3**, 341 (1965).
16E. O. H. Wehrmann, *Physics Fluids* **8**, 1389 (1965).
17E. V. Zakkay and E. Krause, *Int. J. Heat Mass Transfer* **8**, 1047 (1965).

Natural Convection

1F. M. R. Abbott, *Q. Jl Mech. Appl. Math.* **17**, 471 (1964).
2F. Y. E. Bagdasarov, O. D. Kazachkovskii, M. S. Pinkhasik and V. K. Pyshin, *Soviet Atomic Energy* **16**, 503 (1964).
3F. R. F. Barron and L. S. Han, *J. Heat Transfer* **87**, 499 (1965).
4F. F. J. Bayley and G. S. H. Lock, *J. Heat Transfer* **87**, 30 (1965).
5F. J. C. Berg and A. Acrivos, *Chem. Engng Sci.* **20**, 737 (1965).
6F. G. R. Bopp and D. M. Mason, *I/EC Fundamentals* **4**, 222 (1965).
7F. Iu. K. Bratukhin and M. I. Shliomis, *J. Appl. Math. Mech.* **28**, 1160 (1964).
8F. P. M. Brdlik and V. A. Mochalov, *Int. Chem. Engng* **5**, 603 (1965).
9F. G. T. Csanady, *J. Fluid Mech.* **22**, 225 (1965).
10F. N. J. Damaskos and F. J. Young, *Int. J. Heat Mass Transfer* **8**, 721 (1965).
11F. J. W. Deardorff, *Physics Fluids* **8**, 1027 (1965).
12F. J. W. Deardorff and G. E. Willis, *J. Fluid Mech.* **23**, 337 (1965).
13F. D. Dropkin and E. Somerscales, *J. Heat Transfer* **87**, 77 (1965).
14F. J. W. Elder, *J. Fluid Mech.* **23**, 77 (1965).
15F. J. W. Elder, *J. Fluid Mech.* **23**, 99 (1965).
16F. A. Emery and N. C. Chu, *J. Heat Transfer* **87**, 110 (1965).
17F. S. Eshghy, V. S. Arpaci and J. A. Clark, *J. Appl. Mech.* **32**, 183 (1965).
18F. R. M. Fand, *J. Heat Transfer* **87**, 309 (1965).
19F. T. D. Foster, *Physics Fluids* **8**, 1770 (1965).
20F. T. D. Foster, *Physics Fluids* **8**, 1249 (1965).
21F. J. E. Fromm, *Physics Fluids* **8**, 1757 (1965).
22F. W. N. Gill, E. del Casal and D. W. Zeh, *Int. J. Heat Mass Transfer* **8**, 1135 (1965).
23F. W. N. Gill, D. W. Zeh and E. del Casal, *Z. Angew. Math. Phys.* **16**, 539 (1965).
24F. G. H. Gelb and D. Dropkin, *Int. J. Heat Mass Transfer* **8**, 1341 (1965).
25F. R. J. Goldstein, *Chem. Engng Sci.* **19**, 997 (1964).
26F. R. J. Goldstein and D. G. Briggs, *J. Heat Transfer* **86**, 490 (1964).
27F. R. C. Gunness Jr. and B. Gebhart, *Int. J. Heat Mass Transfer* **8**, 43 (1965).
28F. E. W. P. Hahne, *Int. J. Heat Mass Transfer* **8**, 481 (1965).
29F. E. G. Hauptmann, *Int. J. Heat Mass Transfer* **8**, 289 (1965).
30F. R. G. Hering, *Int. J. Heat Mass Transfer* **8**, 1333 (1965).
31F. D. D. Joseph, *Archs Ration. Mech. Analysis* **20**, 51 (1965).
32F. J. C. Y. Koh and J. F. Price, *J. Heat Transfer* **87**, 237 (1965).
33F. U. H. Kurzweg, *Int. J. Heat Mass Transfer* **8**, 35 (1965).
34F. B. H. Lee and P. D. Richardson, *J. Mech. Engng Sci.* **7**, 127 (1965).
35F. R. Lemlich and M. A. Rao, *Int. J. Heat Mass Transfer* **8**, 27 (1965).
36F. W. Lick, *J. Fluid Mech.* **21**, 565 (1965).
37F. F. C. Lockwood and B. W. Martin, *J. Mech. Engng Sci.* **6**, 379 (1964).
38F. D. Lortz, *J. Fluid Mech.* **23**, 113 (1965).
39F. B. W. Martin, *Int. J. Heat Mass Transfer* **8**, 19 (1965).
40F. M. P. Murgai and R. K. Varma, *Int. J. Heat Mass Transfer* **8**, 833 (1965).
41F. E. C. Nickerson, *J. Atmos. Sci.* **22**, 412 (1965).
42F. P. P. Niiler and F. E. Bisshopp, *J. Fluid Mech.* **22**, Part 4, 753 (1965).
43F. G. A. Ostroumov, *Int. J. Heat Mass Transfer* **8**, 259 (1965).
44F. P. D. Richardson, *J. Acoust. Soc. Am.* **36**, 2323 (1964).
45F. P. D. Richardson, *J. Heat Transfer* **87**, 314 (1965).
46F. I. G. Reilly, C. Tien and M. Adelman, *Can. J. Chem. Engng* **43**, 157 (1965).
47F. R. Sani, *J. Fluid Mech.* **20**, 315 (1964).
48F. M. G. Scherberg, *Int. J. Heat Mass Transfer* **8**, 1319 (1965).
49F. A. Schluter, D. Lortz and F. Busse, *J. Fluid Mech.* **23**, 129 (1965).
50F. K. Schwier, *Z. Ver. Dt. Ing.* **107**, 1276 (1965).
51F. L. A. Segel, *J. Fluid Mech.* **21**, 345 (1965).
52F. L. A. Segel, *J. Fluid Mech.* **21**, 359 (1965).
53F. M. I. Shliomis, *J. Appl. Math. Mech.* **28**, 833 (1964).
54F. R. M. Singer, *Z. Angew. Math. Phys.* **16**, 483 (1965).
55F. D. Singh, *Appl. Scient. Res.* **13A**, 437 (1964).
56F. V. M. Soundalgekar, *Indian J. Pure Appl. Phys.* **2**, 360 (1964).
57F. E. M. Sparrow, F. K. Tsou and E. F. Kurtz Jr., *Physics Fluids* **8**, 1559 (1965).
58F. J. Srinivasan, *Appl. Scient. Res.* **11B**, 361 (1965).
59F. J. S. Turner, *Int. J. Heat Mass Transfer* **8**, 759 (1965).
60F. P. van der Dreissche, *J. Fluid Mech.* **23**, 385 (1965).
61F. J. R. Welling and C. B. Wooldridge, *J. Heat Transfer* **87**, 439 (1965).

62F. W. J. YANG and H. C. YEH, *J. Heat Transfer* **87**, 319 (1965).

63F. C. P. YU, *AIAA Jl* **3**, 1184 (1965).

Convection from Rotating Surfaces

1G. P. L. T. BRIAN, R. C. REID and S. W. BODMAN, *A.I.Ch.E. Jl* **11**, 809 (1965).

2G. R. D. CESS, *Appl. Scient. Res.* **A13**, 233 (1964).

3G. L. A. DORFMAN and A. Z. SERAZETDINOV, *Int. J. Heat Mass Transfer* **8**, 317 (1965).

4G. W. W. FOWLIS and R. HIDE, *J. Atmos. Sci.* **22**, 541 (1965).

5G. A. P. GALLAGHER and A. McD. MERCER, *Proc. R. Soc.* **286A**, 117 (1965).

6G. J. P. HARTNETT, SING-HWA TSAI and H. N. JANISCHER, *J. Heat Transfer* **87**, 362 (1965).

7G. A. A. HAYDAY, *J. Heat Transfer* **87**, 445 (1965).

8G. V. M. KAPINOS, *Int. Chem. Engng* **5**, 461 (1965).

9G. S. K. F. KARLSSON and H. A. SNYDER, *Ann. Phys.* **31**, 314 (1965).

10G. S. S. KOONG and P. L. BLACKSHEAR JR., *J. Heat Transfer* **87**, 422 (1965).

11G. M. LITT and G. SERAD, *Chem. Engng Sci.* **19**, 867 (1964).

12G. H. J. LUGT and E. W. SCHWIDERSKI, *Q. Appl. Math.* **23**, 133 (1965).

13G. J. W. MITCHELL and D. E. METZGER, *J. Heat Transfer* **87**, 485 (1965).

14G. W. D. MORRIS, *J. Fluid Mech.* **21**, 453 (1965).

15G. R. F. PATTENDEN, *J. Mech. Engng Sci.* **6**, 144 (1964).

16G. D. K. PETREE, W. L. DUNKLEY and J. M. SMITH, *I/EC Fundamentals* **4**, 171 (1965).

17G. N. RILEY, *Q. J. Mech. Appl. Mech.* **17**, 331 (1964).

18G. F. SALZBERG and S. P. KEZIOS, *J. Heat Transfer* **87**, 469 (1965).

19G. H. A. SYNDER and S. K. F. KARLSSON, *Physics Fluids* **7**, 1696 (1964).

20G. C. L. TIEN, *Int. J. Heat Mass Transfer* **8**, 411 (1965).

21G. C. L. TIEN and I. J. TSUJI, *J. Heat Transfer* **87**, 184 (1965).

22G. J. WALOWIT, S. TSAO and R. C. DI PRIMA, *J. Appl. Mech.* **31**, 585 (1964).

Combined Heat and Mass Transfer

1H. K. B. BISCHOFF and D. M. HIMMELBLAU, *Ind. Engng Chem.* **56**, 61 (1964).

2H. R. J. GOLDSTEIN, G. SHAVIT and T. S. CHEN, *J. Heat Transfer* **87**, 353 (1965).

3H. R. GREIF, *Int. J. Heat Mass Transfer* **8**, 1253 (1965).

4H. T. Y. LI and P. S. KIRK, *Int. J. Heat Mass Transfer* **8**, 1217 (1965).

5H. P. A. LIBBY and M. PIERUCCI, *AIAA Jl* **2**, 2118 (1964).

6H. C. C. PAPPAS and A. F. OKUNO, NASA TN D-2857 (1965).

7H. A. E. SAMUEL and P. N. JOUBERT, *J. Heat Transfer* **87**, 409 (1965).

8H. K. S. SASTRI, *J. Phys. Soc. Japan* **19**, 1385 (1964).

9H. S. M. SCALA and L. M. GILBERT, *AIAA Jl* **3**, 1635 (1965).

10H. D. B. SPALDING, *AIAA Jl* **3**, 965 (1965).

11H. D. B. SPALDING and F. A. CHRISTIE, *Int. J. Heat Mass Transfer* **8**, 511 (1965).

12H. E. M. SPARROW, *Proceedings of the 1964 Heat Transfer Fluid Mechanics Institute*. Stanford University Press, Stanford, Calif. (1964).

13H. E. M. SPARROW, C. J. SCOTT, R. J. FORSTROM and W. A. EBERT, *J. Heat Transfer* **87**, 321 (1965).

14H. B. STEVERDING, *AIAA Jl* **3**, 1245 (1965).

15H. J. L. STOLLERY and A. A. M. EL-EHWANY, *Int. J Heat Mass Transfer* **8**, 55 (1965).

16H. H. TENNEKES, *J. Fluid Mech.* **21**, Part 4, 689 (1965).

17H. H. THOMANN and J. R. BARON, *Int. J. Heat Mass Transfer* **8**, 455 (1965).

18H. D. J. WANOUS and E. M. SPARROW, *J. Heat Transfer* **87**, 317 (1965).

Change of Phase

1J. G. V. ALEKSEEV, B. A. ZEKEVICH and V. I. SUBBOTIN, *Int. Chem. Engng* **5**, 302 (1965).

2J. W. A. BECKMAN and H. MERTE JR., *J. Heat Transfer* **87**, 374 (1965).

3J. G. I. BOBROVICH and N. N. MAMONTOVA, *Int. J Heat Mass Transfer* **8**, 1421 (1965).

4J. V. M. BORISHANSKIY and B. S. FOKIN, *Int. Chem. Engng* **5**, 666 (1965).

5J. R. A. S. BROWN, *Can. J. Chem. Engng* **43**, 217 (1965).

6J. R. A. S. BROWN and G. W. GOVIER, *Can. J. Chem. Engng* **43**, 224 (1965).

7J. R. S. CHAHAL and R. D. MILLER, *Br. J. Appl. Phys.* **16**, 231 (1965).

8J. A. F. CHARWAT, *Int. J. Heat Mass Transfer* **8**, 383 (1965).

9J. J. C. CHATO, *J. Engng Pwr* **87**, 355 (1965).

10J. F. A. CHEEVES, R. G. DRESSLER and W. C. MCGAVOCK, *Ind. Engng Chem.* **4**, 206 (1965).

11J. E. J. DAVIS, *Chem. Engng Sci.* **20**, 265 (1965).

12J. D. E. DRAYER, *I/EC Fundamentals* **4**, 167 (1965).

13J. E. E. DUKE, *Nucl. Sci. Engng* **21**, 490 (1965).

14J. J. A. EDWARDS and J. A. DOOLITTLE, *Int. J. Heat Mass Transfer* **8**, 633 (1965).

15J. J. ESTRIN, T. W. HAYES and T. B. DREW, *A.I.Ch.E. Jl* **11**, 800 (1965).

16J. L. W. FLORSCHUETZ and B. T. CHAO, *J. Heat Transfer* **87**, 209 (1965).

17J. N. A. FRANKEL and S. G. BANKOFF, *J. Heat Transfer* **87**, 95 (1965).

18J. R. F. GAERTNER, *J. Heat Transfer* **87**, 17 (1965).

19J. W. R. GAMBILL, *J. Heat Transfer* **87**, 342 (1965).

20J. G. C. GARDNER, *Int. J. Heat Mass Transfer* **8**, 667 (1965).

21J. L. E. GILL, G. F. HEWITT and P. M. C. LACEY, *Chem. Engng Soc.* **20**, 71 (1965).

22J. G. W. GOVIER, *Can. J. Chem. Engng* **43**, 3 (1965).

23J. P. GRASSMANN, *Kältetechnik* **17**, 42 (1965).

24J. J. R. GRIFFIN and D. R. COUGHANOWR, *A.I.Ch.E. Jl* **11**, 151 (1965).

25J. J. HALLETT, *J. Atmos. Sci.* **22**, 64 (1965).

26J. L. G. HAMBURGER, *Int. J. Heat Mass Transfer* **8**, 1369 (1965).

27J. C. Y. HAN and P. GRIFFITH, *Int. J. Heat Mass Transfer* **8**, 887 (1965).

28J. C. Y. HAN and P. GRIFFITH, *Int. J. Heat Mass Transfer* **8**, 905 (1965).
29J. D. P. HAUGHEY, *Trans. Instn Chem. Engrs* **43**, T40 (1965).
30J. G. F. HEWITT, H. A. KEARSEY, P. M. C. LACEY and D. J. PULLING, *Int. J. Heat Mass Transfer* **8**, 793 (1965).
31J. J. P. HOLMAN, T. W. MOORE and V. M. WONG, *I/EC Fundamentals* **4**, 21 (1965).
32J. G. HORVAY, *Int. J. Heat Mass Transfer* **8**, 195 (1965).
33J. R. HOYLE and D. H. MATTHEWS, *J. Fluid Mech.* **22**, 105 (1965).
34J. G. A. HUGHMARK, *A.I.Ch.E. Jl* **11**, 937 (1965).
35J. G. A. HUGHMARK, *Int. J. Heat Mass Transfer* **8**, 374 (1965).
36J. S. ISHIGAI, M. YAMANE and K. ROKO, *Bull. J.S.M.E.* **8**, 375 (1965).
37J. S. ISHIGAI, M. YAMANE, K. ROKO, T. TAKAGI and K. TANAKA, *Bull. J.S.M.E.* **8**, 383 (1965).
38J. W. KAST, *Z. Ver. Dt. Ing.* **107**, 180 (1965).
39J. J. KATO, *Int. Chem. Engng* **5**, 446 (1965).
40J. S. S. KUTATELADZE, A. I. LEONT'EV and A. G. KIRDYASHKIN, *Int. Chem. Engng* **5**, 474 (1965).
41J. V. K. LA MER and T. W. HEALY, *Science, N.Y.* **148**, 36 (1965).
42J. A. LAPIN, H. C. TOTTEN and L. A. WENZEL, *A.I.Ch.E. Jl* **11**, 503 (1965).
43J. E. J. LE FEVRE and J. W. ROSE, *Int. J. Heat Mass Transfer* **8**, 1117 (1965).
44J. S. LEVY, *J. Heat Transfer* **87**, 53 (1965).
45J. S. LIN, *Kältetechnik* **17**, 138 (1965).
46J. D. N. LYON, M. C. JONES, G. L. RITTER, C. I. CHILADAKIS and P. G. KOSKY, *A.I.Ch.E. Jl* **11**, 773 (1965).
47J. J. MADEJSKI, *Int. J. Heat Mass Transfer* **8**, 155 (1965).
48J. I. G. MALENKOV, *J. Appl. Mech. Tech. Phys.*, No. 6, 292 (1965).
49J. W. MALEWSKI, *Chemie-Ing-Tech.* **37**, 815 (1965).
50J. B. D. MARCUS and D. DROPKIN, *J. Heat Transfer* **87**, 333 (1965).
51J. M. MARKELS JR. and R. L. DURFEE, *A.I.Ch.E. Jl* **11**, 716 (1965).
52J. J. J. MARTIN and J. B. EDWARDS, *A.I.Ch.E. Jl* **11**, 331 (1965).
53J. J. E. MEYER and E. A. REINHARD, *J. Heat Transfer* **87**, 311 (1965).
54J. F. J. MOODY, *J. Heat Transfer* **87**, 134 (1965).
55J. E. M. MOURADIAN and J. E. SUNDERLAND, *Appl. Scient. Res.* **A14**, 431 (1965).
56J. E. M. MOURADIAN and J. E. SUNDERLAND, *Appl. Scient. Res.* **A14**, 453 (1965).
57J. A. N. NAHAVANDI and R. F. VON HOLLEN, *Nucl. Sci. Engng* **22**, 463 (1965).
58J. K. NISHKAWA, H. KUSUDA and K. YAMASAKI, *Bull. J.S.M.E.* **8**, 205 (1965).
59J. S. OSTRACH and A. KOESTEL, *A.I.Ch.E. Jl* **11**, 294 (1965).
60J. V. K. PAI and S. G. BANKOFF, *A.I.Ch.E. Jl* **11**, 65 (1965).
61J. R. F. PARISSE and J. M. KLOSNER, *AIAA Jl* **3**, 777 (1965).
62J. P. A. PAVLOV and V. P. SKRIPOV, *High Temperature* **3**, 97 (1965).
63J. V. N. RADHAKRISHNAN and N. R. KULOOR, *Indian J. Technol.* **3**, 35 (1965).
64J. A. RAUBER, *Z. Ver. Dt. Ing.* **107**, 1228 (1965).
65J. E. RUCKENSTEIN and H. METIU, *Chem. Engng Sci.* **20**, 173 (1965).
66J. T. W. F. RUSSELL and D. E. LAMB, *Can. J. Chem. Engng* **43**, 237 (1965).
67J. H. SCHLICHT, *Kältetechnik* **17**, 47 (1965).
68J. J. T. SCHRODT and E. R. GERHARD, *I/EC Fundamentals* **4**, 46 (1965).
69J. F. L. SCHWARTZ and L. G. SILER, *J. Heat Transfer* **87**, 436 (1965).
70J. S. SIDEMAN and Z. BARSKY, *A.I.Ch.E. Jl* **11**, 539 (1965).
71J. M. A. STYRIKOVICH, E. P. SEROV, O. K. SMIRNOV and P. K. SHARMA, *Soviet Phys. Dokl.* **9**, 541 (1965).
72J. K. SUBBARAYA and N. R. KULOOR, *Indian J. Technol.* **3**, 235 (1965).
73J. D. W. TANNER, D. POPE, C. J. POTTER and D. WEST, *Int. J. Heat Mass Transfer* **8**, 427 (1965).
74J. D. W. TANNER, C. J. POTTER, D. POPE and D. WEST, *Int. J. Heat Mass Transfer* **8**, 419 (1965).
75J. J. S. TURTON, *Int. J. Heat Mass Transfer* **8**, 1425 (1965).
76J. A. UMUR and P. GRIFFITH, *J. Heat Transfer* **87**, 275 (1965).
77J. W. R. VAN WIJK and S. J. D. VAN STRALEN, *Chemie-Ingr-Tech.* **37**, 509 (1965).
78J. H. R. VELKOFF and J. H. MILLER, *J. Heat Transfer* **87**, 197 (1965).
79J. P. C. WAYNER JR. and S. G. BANKOFF, *A.I.Ch.E. Jl* **11**, 59 (1965).
80J. P. C. WAYNER JR. and A. S. KESTEN, *A.I.Ch.E. Jl* **11**, 858 (1965).
81J. N. ZUBER and J. A. FINDLAY, *J. Heat Transfer* **87**, 453 (1965).

Radiation

1K. G. W. AUTIO and E. SCALA, *AIAA Jl* **3**, 738 (1965).
2K. JEAN M. BENNETT and E. J. ASHLEY, *Appl. Optics* **4**, 221 (1965).
3K. J. J. BERNARD and J. GENOT, *Int. J. Heat Mass Transfer* **8**, 449 (1965).
4K. J. T. BEVANS and D. K. EDWARDS, *J. Heat Transfer* **87**, 388 (1965).
5K. R. C. BIRKEBAK and E. R. G. ECKERT, *J. Heat Transfer* **87**, 85 (1965).
6K. J. R. BRANSTETTER, NASA TN D-2902 (1965).
7K. E. A. BRUN, M. CLOUPEAU and N. THO-NHAN, *Astronautica Acta* **11**, 43 (1965).
8K. R. D. CESS and A. E. SOTAK, *Z. Angew. Math. Phys. Math. Phys.* **15**, 642 (1964).
9K. J. H. CHIN and S. W. CHURCHILL, *J. Heat Transfer* **87**, 167 (1965).
10K. I. M. COHEN, *AIAA Jl* **3**, 981 (1965).
11K. D. L. COMPTON and D. M. COOPER, *AIAA Jl* **3**, 107 (1965).
12K. D. K. EDWARDS and J. T. BEVANS, *AIAA Jl* **3**, 1323 (1965).
13K. L. B. EVANS, C. M. CHU and S. W. CHURCHILL, *J. Heat Transfer* **87**, 381 (1965).

14K. D. L. FAIN, *J. Opt. Soc. Am.* **55**, 460 (1965).
15K. J. E. FONTENOT JR., *AIAA Jl* **3**, 970 (1965).
16K. R. GREIF, *AIAA Jl* **3**, 98 (1965).
17K. R. GREIF, *AIAA Jl* **3**, 1340 (1965).
18K. A. C. HALL, *J. Opt. Soc. Am.* **55**, 911 (1965).
19K. M. A. HEASLET and F. B. FULLER, NASA TN D-2515 (1964).
20K. M. A. HEASLET and R. F. WARMING, *Int. J. Heat Mass Transfer* **8**, 979 (1965).
21K. B. M. HERMAN and S. R. BROWNING, *J. Atmos. Sci.* **22**, 559 (1965).
22K. R. R. HIBBARD, NASA TN D-2751 (1965).
23K. B. J. HISDAL, *J. Opt. Soc. Am.* **55**, 1122 (1965).
24K. B. J. HISDAL, *J. Opt. Soc. Am.* **55**, 1255 (1965).
25K. H. HOSHIZAKI and K. H. WILSON, *AIAA Jl* **3**, 1614 (1965).
26K. H. HOSHIZAKI and K. H. WILSON, *AIAA Jl* **3**, 1614 (1965).
27K. H. C. HOTTEL and A. F. SAROFIM, *Int. J. Heat Mass Transfer* **8**, 1153 (1965).
28K. L. R. JONES, *J. Heat Transfer* **87**, 421 (1965).
29K. K. KAST, *Z. Ver. Dt. Ing.* **107**, 638 (1965).
30K. F. J. KELLY and D. G. MOORE, *Appl. Optics* **4**, 31 (1965).
31K. J. C. Y. KOH, *Int. J. Heat Mass Transfer* **8**, 373 (1965).
32K. W. LICK, *Int. J. Heat Mass Transfer* **8**, 119 (1965).
33K. S. H. LIN and E. M. SPARROW, *Appl. Optics* **4**, 277 (1965).
34K. S. H. LIN and E. M. SPARROW, *J. Heat Transfer* **87**, 299 (1965).
35K. T. J. LOVE and R. J. GROSH, *J. Heat Transfer* **87**, 161 (1965).
36K. T. W. MULLIKIN, *J. Soc. Ind. Appl. Math.* **13**, 388 (1965).
37K. S. S. R. MURTY, *Int. J. Heat Mass Transfer* **8**, 1203 (1965).
38K. L. D. NICHOLS, *Int. J. Heat Mass Transfer* **8**, 589 (1965).
39K. F. E. NICODEMUS, *Appl. Optics* **4**, 767 (1965).
40K. D. B. OLFE, *AIAA Jl* **2**, 1928 (1964).
41K. L. G. POLGAR and J. R. HOWELL, NASA TN D-2904 (1965).
42K. H. POLTZ, *Int. J. Heat Mass Transfer* **8**, 515 (1965).
43K. P. J. RICHETTA, *J. Opt. Soc. Am.* **55**, 21 (1965).
44K. CAROL J. SATOS and N. O. STOCKMAN, NASA TN D-2556 (1964).
45K. R. A. SEBAN, *J. Heat Transfer* **87**, 173 (1965).
46K. E. M. SPARROW, *Appl. Optics* **4**, 41 (1965).
47K. E. M. SPARROW and A. HAJI-SHEIKH, *J. Heat Transfer* **87**, 103 (1965).
48K. E. M. SPARROW and S. H. LIN, *Int. J. Heat Mass Transfer* **8**, 769 (1965).
49K. R. P. STEIN, *J. Heat Transfer* **87**, 316 (1965).
50K. G. W. STUART and W. G. VULLIET, *Physics Fluids* **8**, 663 (1965).
51K. P. D. THOMAS, *AIAA Jl* **3**, 1401 (1965).
52K. K. E. TORRANCE and E. M. SPARROW, *J. Heat Transfer* **87**, 283 (1965).
53K. S. C. TRAUGOTT, *Physics Fluids* **8**, 834 (1965).
54K. R. VISKANTA, *J. Heat Transfer* **87**, 143 (1965).
55K. R. VISKANTA, *Appl. Scient. Res.* **A13**, 291 (1964).
56K. K. C. WANG, *J. Fluid Mech.* **20**, 447 (1964).

Liquid Metals

1L. J. A. ALBERS and R. P. MACOSKO, NASA TN D-2838 (1965).
2L. V. M. BORISHANSKII and E. V. FIRSOVA, *Soviet Atomic Energy* **16**, 562 (1964).
3L. V. M. BORISHANSKII, T. V. ZABLOTSKAYA and N. I. IVANCHENKO, *Soviet Atomic Energy* **16**, 649 (1964).
4L. O. E. DWYER, *Nucl. Sci. Engng* **21**, 79 (1965).
5L. O. E. DWYER and P. S. TU, *Nucl. Sci. Engng* **21**, 90 (1965).
6L. C. J. HSU, *Int. J. Heat Mass Transfer* **8**, 303 (1965).
7L. E. R. G. ECKERT and D. C. PETERSON, *J. Heat Transfer* **87**, 419 (1965).
8L. A. KOESTEL, M. U. GUSTEIN and R. I. WAINWRIGHT NASA TN D-2514 (1964).
9L. B. NIMMO and O. E. DWYER, *J. Heat Transfer* **87**, 312 (1965).
10L. E. SKUPINSKI, J. TORTEL and L. VAUTREY, *Int. J. Heat Mass Transfer* **8**, 937 (1965).

Low-density Heat Transfer

1M. A. M. CLAUSING and B. T. CHAO, *J. Heat Transfer* **87**, 243 (1965).
2M. E. FRIED and H. L. ATKINS, *J. Spacecraft Rockets* **2**, 591 (1965).
3M. H. GRAD, *J. Soc. Ind. Appl. Math.* **13**, 259 (1965).
4M. A. V. IVANOV, *Soviet Phys. Dokl.* **10**, 191 (1965).
5M. L. LEES, *J. Soc. Ind. Appl. Math.* **13**, 278 (1965).
6M. J. A. MORRISON and Y. TUZI, *J. Vacuum Sci. Tech.* **2**, 109 (1965).
7M. G. N. PATTERSON, *AIAA Jl* **3**, 577 (1965).
8M. S. J. ROBERTSON, *Physics Fluids* **8**, 539 (1965).
9M. H. SHIN, *J. Chem. Phys.* **42**, 3442 (1965).
10M. Y. SONE, *J. Phys. Soc. Japan* **20**, 222 (1965).
11M. G. S. SPRINGER and R. RATONYI, *J. Heat Transfer* **87**, 493 (1965).
12M. G. S. SPRINGER and S. W. TSAI, *Physics Fluids* **8**, 1561 (1965).
13M. E. V. STUPOCHENKO, *Proc. Acad. Sci. USSR* **163**, 849 (1965).
14M. C. H. SU, *Physics Fluids* **7**, 1867 (1964).
15M. T. D. TAYLOR, *Physics Fluids* **7**, 1885 (1964).
16M. B. TRICHET and J. GOSSE, *C. R. Hebd. Séanc. Acad. Sci., Paris* **260**, 4041 (1965).
17M. S. V. VALLANDER, *Soviet Phys. Dokl.* **10**, 389 (1965).
18M. H. Y. WACHMAN, *J. Chem. Phys.* **42**, 1850 (1965).
19M. D. R. WILLIS, *Physics Fluids* **8**, 1908 (1965).

Measurement Techniques

1N. R. L. ANDERSON and L. A. GUILDNER, *Rev. Scient. Instrum.* **36**, 615 (1965).
2N. R. C. BACHMANN, J. T. CHAMBERS and W. H. GIEDT, *ISA Trans.* **4**, 143 (1965).
3N. B. BERNARD, *Instrums Control Syst.* **38**, 113 (1965).
4N. R. BESSOUAT, H. CHAVANEL and S. ELBERG, *Journal de Physique* **26**, 1A (1965).

5N. M. BOËL and B. ERICKSON, *Rev. Scient. Instrum.* **36**, 904 (1965).
6N. G. BOOM and F. VAN DER WOUDE, *Rev. Scient. Instrum.* **36**, 857 (1965).
7N. J. B. BRACKENBRIDGE and W. P. GILBERT, *Appl. Optics* **4**, 819 (1965).
8N. F. R. CALDWELL, *Engng Instrum.* **69C**, 95 (1965).
9N. R. L. CARTER, P. D. MAYCOCK, A. H. KLEIN and G. C. DANIELSON, *J. Appl. Phys.* **36**, 2333 (1965).
10N. R. A. COOKSON, P. G. DUNHAM and J. K. KILHAM, *Combust. Flame* **8**, 168 (1964).
11N. R. A. COOKSON, P. G. DUNHAM and J. K. KILHAM, *J. Scient. Instrum.* **42**, 260 (1965).
12N. C. O. DENGLER, *Instrums Control Syst.* **38**, 117 (1965).
13N. A. A. R. EL AGIB, *J. Scient. Instrum.* **41**, 592 (1964).
14N. R. J. EXTON, NASA TN D-2660 (1965).
15N. C. FELDMAN, *Instrums Control Syst.* **38**, 101 (1965).
16N. I. B. FOGELSON, *Measmt Tech., Pittsb.*, No. 12, 1053 (1964).
17N. M. GASTER, *J. Fluid Mech.* **20**, Part 2, 183 (1964).
18N. W. H. GIEDT and J. T. CHAMBERS, *J. Heat Transfer* **87**, 397 (1965).
19N. R. J. GOLDSTEIN, *Rev. Scient. Instrum.* **36**, 1408 (1965).
20N. J. GREY, *ISA Trans.* **4**, 102 (1965).
21N. J. L. HALES and E. F. G. HERINGTON, *J. Scient. Instrum.* **42**, 203 (1965).
22N. J. T. JENSEN, J. KLEBANOFF and G. A. HAAS, *Rev. Scient. Instrum.* **35**, 1717 (1964).
23N. D. L. JOHNSON, *ISA Trans.* **4**, 46 (1965).
24N. J. P. JOHNSTON, *J. Bas. Engng* **86**, 907 (1964).
25N. R. A. JONES and J. L. HUNT, *J. Spacecraft Rockets* **2**, 632 (1965).
26N. P. G. KAFKA, J. GAZ and W. T. YEE, *J. Spacecraft Rockets* **2**, 475 (1965).
27N. O. KAMADA, *Appl. Optics* **3**, 1397 (1964).
28N. R. LETAN and E. KEHAT, *Chem. Engng Sci.* **20**, 856 (1965).
29N. I. I. KIRENKOV, *Measmt Tech., Pittsb.*, No. 4, 330 (1964).
30N. P. J. KLASS, *Aviat. Week* **82**, 75 (1965).
31N. M. R. LAUVER, J. L. HALL and F. E. BELLES, NASA TN D-2955 (1965).
32N. A. LEVY, *J. Scient. Instrum.* **41**, 449 (1964).
33N. E. A. LEZBERG and D. R. BUCHELE, NASA TN D-2441 (1964).
34N. W. F. MERZKIRCH, *AIAA Jl* **3**, 1974 (1965).
35N. W. F. MERZKIRCH, *AIAA Jl* **3** 794 (1965).
36N. J. MIDDLEHURST, P. W. BOARD and R. G. P. ELBOURNE, *J. Scient. Instrum.* **41**, 676 (1964).
37N. P. P. NIILER, *Rev. Scient. Instrum.* **36**, 921 (1965).
38N. V. C. PATEL, *J. Fluid Mech.* **23**, Part 1, 185 (1965).
39N. J.-L. PEUBE, *C. R. Hebd. Séanc. Acad. Sci., Paris* **259**, 3180 (1964).
40N. A. QUARMBY, *Jl R. Aeronaut. Soc.* **68**, 696 (1964).
41N. E. REISMAN and P. M. SUTTON, *Appl. Optics* **4**, 144 (1965).
42N. P. D. RICHARDSON, *Int. J. Heat Mass Transfer* **8**, 557 (1965).
43N. A. J. SABADELL, J. WENOGRAD and M. SUMMERFIELD, *AIAA Jl* **3**, 1580 (1965).
44N. M. SAJBEN, *Rev. Scient. Instrum.* **36**, 945 (1965).
45N. F. A. SCHRAUB, S. J. KLINE, J. HENRY, P. W. RUNSTADLER JR. and A. LITTELL, *J. Bas. Engng* **87**, 429 (1965).
46N. A. SEGINER, A. COHEN and J. ROM, *Israel J. Technol.* **3**, 25 (1965).
47N. A. SIGALIA, *AIAA Jl* **3**, 1531 (1965).
48N. J. R. STERRETT, J. C. EMERY and J. B. BARBER, *AIAA Jl* **3**, 963 (1965).
49N. H. VAN DIJK, *Physica, 's Grav.* **30**, 1498 (1964).
50N. J. E. S. VENART, *J. Scient. Instrum.* **41**, 727 (1964).
51N. J. A. VEPREK, *J. Scient. Instrum.* **42**, 252 (1965).
52N. B. E. WALKER JR., C. T. EWING and R. R. MILLER, *Rev. Scient. Instrum.* **36**, 816 (1965).
53N. B. E. WALKER JR., C. T. EWING and R. R. MILLER, *Rev. Scient. Instrum.* **36**, 601 (1965).
54N. M. WAXMAN and W. T. CHEN, *J. Res. Natn. Bur. Stand.* **C69**, 27 (1965).
55N. A. R. WAZZAN, A. M. O. SMITH and R. C. LIND, *Physics Fluids* **8**, 1641 (1965).
56N. I. WEINSTEIN and R. R. HOWELL, NASA TN D-2769 (1965).
57N. A. A. ZENIN, *J. Appl. Mech. Tech. Phys.*, p. 203 (February 1965).

Heat Exchangers

1P. W. BERGWERK, *Br. Chem. Engng* **10**, 323 (1965).
2P. F. S. CHAPMAN, N. DALLENBACH and F. A. HOLLAND, *Trans. Instn Chem. Engrs* **42**, 398 (1964).
3P. I. C. FINLAY and Miss N. DALGLEISH, *J. Mech. Engng Sci.* **7**, 318 (1965).
4P. R. E. GITHENS, W. R. MINOR and V. J. TOMSIC, *Chem. Engng Prog.* **61**, 55 (1965).
5P. R. GREGORIE, *Chemie-Ing-Tech.* **37**, 956 (1965).
6P. R. GREGORIE and H. WEGNER, *Chemie-Ingr-Tech.* **37**, 524 (1965).
7P. M. T. HADDAD, *Rev. Gén. Thermique* **3**, 1251 (1964).
8P. G. HANSON and J. INGHAM, *Br. Chem. Engng* **10**, 391 (1965).
9P. P. HARRIOTT and H. WIEGANDT, *A.I.Ch.E. Jl* **10**, 755 (1964).
10P. G. HELKE, *Z. Ver. Dt. Ing.* **107**, 409 (1965).
11P. C. P. HOWARD, *J. Engng Pwr* **87**, 72 (1965).
12P. S. KAO, *J. Heat Transfer* **87**, 202 (1965).
13P. D. W. KIRKLEY and I. N. MOMTCHILOFF, *Br. Chem. Engng* **10**, 31 (1965).
14P. V. V. G. KRISHNAMURTY and C. V. RAO, *Indian J. Technol.* **2**, 325 (1964).
15P. R. LETAN and E. KEHAT, *A.I.Ch.E. Jl* **11**, 804 (1965).
16P. D. V. SAGAR, T. K. RAMANUJAM, V. V. G. KRISHNAMURTY and C. V. RAO, *Indian J. Technol.* **3**, 79 (1965).
17P. F. SCHULENBERG, *Chemie-Ingr-Tech.* **37**, 799 (1965).
18P. B. E. SHORT, *Chem. Engng Prog.* **61**, 63 (1965).
19P. A. H. P. SKELLAND, W. K. BLAKE, J. W. DABROWSKI, J. A. ULRICH and T. F. MACH, *A.I.Ch.E. Jl* **11**, 951 (1965).
20P. F. P. STAINTHORP and A. G. AXON, *Chem. Engng Sci.* **20**, 107 (1965).
21P. F. STREK, S. MASIUK, G. GAWOR and R. JAGIELLO, *Int. Chem. Engng* **5**, 695 (1965).
22P. F. TREFNY, *Chemie-Ingr-Tech.* **37**, 501 (1965).

23P. F. TREFNY, *Chemie-Ingr-Tech.* **37**, 835 (1965).
24P. T. W. WEBER and P. HARRIOTT, *I/EC Fundamentals* **4**, 155 (1965).

Aircraft and Space Vehicles

1Q. H. J. ALLEN, B. S. BALDWIN JR. and N. A. JAMES, NASA TN D-2872 (1965).
2Q. R. P. BOBCO, *J. Engng Pwr* **87**, 259 (1965).
3Q. B. T. CHAO and G. L. WEDEKIND, *J. Spacecraft Rockets* **2**, 146 (1965).
4Q. J. F. CONEYBEAR and H. R. KROEGER, *J. Spacecraft Rockets* **2**, 98 (1965).
5Q. J. E. FONTENOT JR., *AIAA Jl* **3**, 970 (1965).
6Q. W. L. FRANCIS, *J. Spacecraft Rockets* **2**, 630 (1965).
7Q. H. C. HALLER, S. LIEBLEIN and B. G. LINDOW, NASA TN D-2836 (1965).
8Q. G. M. HANLEY and F. J. LYON, *J. Spacecraft Rockets* **2**, 508 (1965).
9Q. P. HRYCAK, *Astronautica Acta* **10**, 314 (1965).
10Q. J. J. KAUZLARICH, *J. Appl. Mech.* **32**, 177 (1965).
11Q. E. L. KRAMER and S. GRONICH, *J. Spacecraft Rockets* **2**, 345 (1965).
12Q. G. C. LORENZ, *AIAA Jl* **3**, 774 (1965).
13Q. J. H. LUNDELL, R. M. WAKEFIELD and J. W. JONES, *AIAA Jl* **3**, 2087 (1965).
14Q. H. MAY, *J. Engng Pwr* **87**, 57 (1965).
15Q. A. J. MCDONALD and P. O. HEDMAN, *AIAA Jl* **3**, 1250 (1965).
16Q. B. I. REZNIKOV, *Int. Chem. Engng* **5**, 552 (1965).
17Q. MARY F. ROMIG, *AIAA Jl* **3**, 385 (1965).
18Q. A. V. SAULE, R. P. KREBS and B. M. AUER, NASA TN D-2839 (1965).
19Q. R. N. SCHMIDT, *J. Spacecraft Rockets* **2**, 101 (1965).
20Q. R. N. SCHMIDT and K. C. PARK, *Appl. Optics* **4**, 917 (1965).
21Q. C. W. STROUD, NASA TN D-2876 (1965).
22Q. M. F. TAYLOR and J. V. MILLER, NASA TN D-2594 (1965).
23Q. L. A. WALKER and E. MARKLAND, *Int. J. Heat Mass Transfer* **8**, 729 (1965).
24Q. R. G. WATTS, *J. Heat Transfer* **87**, 369 (1965).
25Q. J. P. WEIDNER and J. M. CUBBAGE, NASA TN D-2929 (1965).
26Q. D. A. WILLOUGHBY, *J. Spacecraft Rockets* **2**, 239 (1965).

Thermodynamic and Transport Properties

1R. A. ABE and P. J. FLORY, *J. Am. Chem. Soc.* **87**, 1838 (1965).
2R. W. F. AHYTE, *Physics Fluids* **8**, 1918 (1965).
3R. A. AKSARAILLIAN and O. CERCEAU, *Acta Scient. Venezolana* **16**, 54 (1965).
4R. KH. I. AMIRKHANOV, G. V. STEPANOV and B. A. MURSALOV, *Dokl. Akad. Nauk SSSR* **163**, 1189 (1965).
5R. S. ARAJS, B. F. OLIVER and G. R. DUNMYER, *J. Appl. Phys.* **36**, 2210 (1965).
6R. E. W. ARNOLD, D. W. LIOU and J. W. ELDRIDGE, *J. Chem. Engng Data* **10**, 88 (1965).
7R. H. D. BAEHR and H. THURMER, *Brennst.—Wärme-Kraft* **17**, 20 (1965).
8R. O. P. BAHETHI and S. C. SAXENA, *Indian J. Pure Appl. Phys.* **3**, 12 (1965).
9R. C. B. BAKER and N. DE HAAS, *Physics Fluids* **7**, 1400 (1964).
10R. A. M. BANAEV and V. YA CHEKHOVSKOI, *High Temperature* **3** 47 (1965).
11R. W. BARHO, *Kältetechnik* **17**, 219 (1965).
12R. A. BEN-NAIM, *J. Chem. Phys.* **42**, 1512 (1965).
13R. K. E. BETT and J. B. CAPPI, *Nature, Lond.* **207**, 620 (1965).
14R. W. BOTCH and M. FIXMAN, *J. Chem. Phys* **42**, 196 (1965).
15R. J. BREWER, *J. Chem. Engng Data* **10**, 113 (1965).
16R. D. BREZING, *AIAA Jl* **3**, 1422 (1965).
17R. O. C. BRIDGEMAN and E. W. ALDRICH, *J. Heat Transfer* **87**, 266 (1965).
18R. R. S. BROKAW, *Int. J. Engng Sci.* **3**, 251 (1965).
19R. R. S. BROKAW, *J. Chem. Phys.* **42**, 1140 (1965)
20R. S. G. BRUSH, *J. Chem. Phys.* **42**, 792 (1965).
21R. R. A. BUCKINGHAM, J. W. FIX and E. GAL, *Proc. R. Soc.* **A284**, 237 (1965).
22R. D. BURNETT, *J. Chem. Phys.* **42**, 2533 (1965).
23R. M. CAMAC and R. M. FEINBERG, *J. Fluid Mech.* **21**, 673 (1965).
24R. F. B. CANFIELD, T. W. LELAND and R. KOBAYASHI, *J. Chem. Engng Data* **10**, 92 (1965).
25R. A. CEZAIRLIYAN and Y. S. TOULOUKIAN, *High Temperature* **3**, 63 (1965).
26R. N. H. CHEN, *J. Chem. Engng Data* **10**, 207 (1965).
27R. D. J. COLLINS, R. GRIEF and A. E. BRYSON JR., *Int. J. Heat Mass Transfer* **8**, 1209 (1965).
28R. D. W. CONDIFF, W.-K. LU and J. S. DAHLER, *J Chem. Phys.* **42**, 3445 (1965).
29R. D. J. CRONIN, *Am. J. Phys.* **33**, 835 (1965).
30R. C. F. CURTISS, M. B. MCELROY and D. K. HOFFMAN, *Int. J. Engng Sci.* **3**, 269 (1965).
31R. A. J. B. CUTLER and J. A. MORRISON, *Trans. Faraday Soc.* **61**, 429 (1965).
32R. S. P. DASTUR and G. THODOS, *Can. J. Chem. Engng* **43**, 73 (1965).
33R. R. H. DAVIES, E. A. MASON and R. J. MUNN, *Physics Fluids* **8**, 444 (1965).
34R. A. E. DE VRIES and A. HARING, *Z. Naturf.* **A20**, 433 (1965).
35R. F. DIN and I. BURN, *Trans. Faraday Soc.* **61**, 1351 (1965).
36R. M. DIXON, F. E. HOARE, T. M. HOLDEN and D. E. MOODY, *Proc. R. Soc.* **A285**, 561 (1965).
37R. F. J. DU CHATENIER, B. M. BOERSTOEL and J. DE NOBEL, *Physica, 's Grav.* **31**, 1061 (1965).
38R. O. EKINER and G. THODOS, *Can. J. Chem. Engng* **43**, 205 (1965).
39R. M. H. ERNST, J. R. DORFMAN and E. G. D. COHEN, *Physica, 's Grav.* **31**, 493 (1965).
40R. R. EVANGELISTI and F. ISACCHINI, *Int. J. Heat Mass Transfer* **8**, 1303 (1965).
41R. P. FAUCHAIS and N. MANSON, *C. R. Hebd. Séanc. Acad. Sci., Paris* **260**, 2729 (1965).
42R H. L. FRISCH and B. BERNE, *J. Chem. Phys.* **43**, 250 (1965)

43R. J. M. GANDHI and S. C. SAXENA, *Indian J. Pure Appl. Phys.* **3**, 312 (1965).
44R. A. V. GROSS, *Science, N.Y.* **147**, 1438 (1965).
45R. E. A. GUGGENHEIM, *Molec. Phys.* **9**, 199 (1965).
46R. A. DAS GUPTA and A. K. BARUA, *J. Chem. Phys.* **42**, 2849 (1965).
47R. B. B. HAMEL, *Physics Fluids* **8**, 418 (1965).
48R. R. W. HAYWOOD, *J. Engng Pwr* **87**, 93 (1965).
49R. C. E. HECHT, *J. Chem. Phys.* **42**, 2862 (1965).
50R. F. J. HEINZELMANN, D. T. WASAN and C. R. WILKE, *I/EC Fundamentals* **4**, 55 (1965).
51R. D. HENDERSON, *A. Rev. Phys. Chem.* **15**, 31 (1964).
52R. C. N. HOOKER, A. R. UBBELOHDE and D. A. YOUNG, *Proc. R. Soc.* **A284**, 17 (1965).
53R. E. R. HIGGINS and J. LIELMEZS, *J. Chem. Engng Data* **10**, 178 (1965).
54R. W. G. HOOVER and F. H. REE, *J. Chem. Phys.* **43**, 375 (1965).
55R. P. JESCHKE, *Z. Ver. Dt. Ing.* **107**, 181 (1965).
56R. R. K. JOSHI and S. C. SAXENA, *J. Scient. Ind. Res.* **24**, 21 (1965).
57R. R. K. JOSHI and S. C. SAXENA, *Physica, 's Grav.* **31**, 762 (1965).
58R. J. Z. KASAVCHINSKII, *Dokl. Akad. Nauk SSSR* **161**, 1127 (1965).
59R. P. M. KESSEL'MAN, *High Temperature* **2**, 791 (1964).
60R. J. KESTIN, *J. Engng Pwr* **87**, 87 (1965).
61R. F. G. KEYES and R. G. VINES, *J. Heat Transfer* **87**, 177 (1965).
62R. S. KIELICH, *Physica, 's Grav.* **31**, 444 (1965).
63R. S. R. KIM and J. ROSS, *J. Chem. Phys.* **42**, 263 (1965).
64R. L. T. KOTOUSOV, *Soviet Phys. Tech. Phys.* **9**, 1694 (1965).
65R. E. KUSS, *Chemie-Ingr-Tech.* **37**, 465 (1965).
66R. B. LATTO, *Int. J. Heat Mass Transfer* **8**, 689 (1965).
67R. A. J. LEADBETTER, *Proc. R. Soc.* **A287**, 403 (1965).
68R. A. I. LEE and R. T. ELLINGTON, *J. Chem. Engng Data* **10**, 101 (1965).
69R. B. LE NEINDRE, P. JOHANNIN and B. VODAR, *C. R. Hebd. Séanc. Acad. Sci., Paris* **261**, 63 (1965).
70R. D. A. LENNERT and G. THODOS, *I/EC Fundamentals* **4**, 139 (1965).
71R. I. LICEA, *Physica Status Solidi* **10**, K115 (1965).
72R. S. MALLIKARJUN and N. E. HILL, *Trans. Faraday Soc.* **61**, 1389 (1965).
73R. C. E. MALLON and M. CUTLER, *Rev. Scient. Instrum.* **36**, 1036 (1965).
74R. V. A. MALYSHEV, *Bull. Inst. Higher Education—Physics*, No. 4, 144 (1965).
75R. R. MARCHAL, R. DEIMAS and A. WOHLGROTH, *C. R. Hebd. Séanc. Acad. Sci., Paris* **261**, 2067 (1965).
76R. S. MATHUR and S. C. SAXENA, *Br. J. Appl. Phys.* **16**, 389 (1965).
77R. G. P. MATHUR and G. THODOS, *A.I.Ch.E. Jl* **11**, 164 (1965).
78R. F. R. MCCOURT and R. F. SNIDER, *J. Chem. Phys.* **43**, 2276 (1965).
79R. P. G. MENON, *Indian J. Pure Appl. Phys.* **3**, 334 (1965).
80R. D. MISIC and G. THODDOS, *A.I.Ch.E. Jl* **11**, 650 (1965).
81R. L. MONCHICK, E. A. MASON, R. J. MUNN and F. J. SMITH, *Phys. Rev.* **139**, 1076 (1965).
82R. L. MONCHICK, A. N. G. PEREIRA and E. A. MASON, *J. Chem. Phys.* **42**, 3241 (1965).
83R. T. E. MORSY, *Kältetechnik* **17**, 86 (1965).
84R. R. J. MUNN, E. A. MASON and F. J. SMITH, *Physics Fluids* **8**, 1103 (1965).
85R. I. NAGATA, *Can. J. Chem. Engng* **43**, 84 (1965).
86R. I. NAGATA, *J. Chem. Engng Data* **10**, 106 (1965).
87R. G. NARSIMHAN, *Indian J. Technol.* **3**, 230 (1965).
88R. G. NARSIMHAN, *Br. Chem. Engng* **10**, 253 (1965).
89R. G. NARSIMHAN, *Indian J. Technol.* **3**, 294 (1965).
90R. Y. M. NAZIEV, *Zh. Fiz. Khim.* **39**, 1359 (1965).
91R. D. P. NEEDHAM and H. ZIEBLAND, *Int. J. Heat Mass Transfer* **8**, 1387 (1965).
92R. D. F. OTHMER and H. N. HUANG, *Ind. Engng Chem.* **57**, 42 (1965).
93R. R. PAUL, A. J. HOWARD and W. W. WATSON, *J. Chem. Phys.* **43**, 1890 (1965).
94R. D. B. PFENNING, F. B. CANFIELD and R. KOBAYASHI, *Chem. Engng Data* **10**, 9 (1965).
95R. D. B. PFENNING, F. B. CANFIELD and R. KOBAYASHI, *J. Chem. Engng Data* **10**, 57 (1965).
96R. H. POLTZ, *Int. J. Heat Mass Transfer* **8**, 609 (1965).
97R. R. W. POWELL, *Int. J. Heat Mass Transfer* **8**, 1033 (1965).
98R. R. W. POWELL, R. P. TYE and M. J. HICKMAN, *Int. J. Heat Mass Transfer* **8**, 679 (1965).
99R. G. ACHUTA RAMAYYA and N. R. KULOOR, *Indian J. Chem.* **3**, 293 (1965).
100R. R. V. GOPALA RAO, *Indian J. Pure Appl. Phys.* **3**, 233 (1965).
101R. TERESA S. REE, T. REE, H. EYRING and R. PERKINS, *J. Phys. Chem., Ithaca* **69**, 3322 (1965).
102R. W. REESE and J. E. TUCKER, *J. Chem. Phys.* **43**, 105 (1965).
103R. R. C. REID and T. W. LELAND JR., *A.I.Ch.E. Jl* **11**, 228 (1965).
104R. D. N. RIHANI and L. K. DORAISWAMY, *I/EC Fundamentals* **4**, 17 (1965).
105R. R. L. ROBINSON JR., W. C. EDMISTER and F. A. L. DULLIEN, *J. Phys. Chem.* **69**, 258 (1965).
106R. T. S. ROE, T. REE and H. EYRING, *J. Phys. Chem.* **68**, 3262 (1964).
107R. J. C. ROSSI and F. DANON, *J. Chem. Phys.* **43**, 762 (1965).
108R. J. S. ROWLINSON, *Molec. Phys.* **9**, 197 (1965).
109R. J. R. SMAS, *Molec. Phys.* **9**, 17 (1965).
110R. M. P. SAKSENA and S. C. SAXENA, *Phys. Rev. Lett.* **18**, 120 (1965).
111R. S. C. SAXENA, M. P. SAKSENA, R. S. GAMBHIR and J. M. GANDHI, *Physica, 's Grav.* **31**, 333 (1965).
112R. S. C. SAXENA and B. P. MATHUR, *Rev. Mod. Phys.* **37**, 316, (1965).
113R. J. V. SENGERS, *Int. J. Heat Mass Transfer* **8**, 1103 (1965).
114R. J. V. SENGERS, *Phys. Rev. Lett.* **15**, 515 (1965).
115R. R. L. SHANK, *ASHRAE Jl* **7**, 94 (1965).
116R. I. I. SHERIF, *Appl. Scient. Res.* **A14**, 353 (1964–65).
117R. R. H. SHERMAN, *Phys. Rev. Lett.* **15**, 141 (1965).

118R. H. A. SIMON, C. S. LIU and J. P. HARTNETT, *Int. J Heat Mass Transfer* **8**, 1176 (1965).
119R. F. J. SMITH, E. A. MASON and R. J. MUNN, *J. Chem. Phys.* **42**, 1334 (1965).
120R. E. SPINNER, *J. Chem. Phys.* **42**, 812 (1965).
121R. D. STRAUB, A. SCHABER and T. E. MORSY, *Kältetechnik* **17**, 212 (1965).
122R. L. TISZA and C. E. CHASE, *Phys. Rev. Lett* **15**, 4 (1965).
123R. N. B. VARGAFTIK and N. KH. ZIMINA, *High Temperature* **2**, 782 (1964).
124R. J. E. S. VENART, *J. Chem. Engng Data* **10**, 239 (1965).
125R. D. S. VISWANATH, *Indian J. Technol.* **3**, 295 (1965).
126R. D. S. VISWANATH, *J. Scient. Ind. Res.* **24**, 374 (1965).
127R. A. V. VORONEL', V. G. SNIGIREV and YU. R. CHASHKIN, *Soviet Phys. JETP* **21**, 653 (1965).
128R. A. WILLIAMS, *J. Mech. Engng Sci.* **7**, 335 (1965).
129R. J. N. WILSON, *J. Chem. Phys.* **43**, 2564 (1965).
130R. O. W. WITZELL and J. W. JOHNSON, *ASHRAE Jl* **7** 55 (1965).