Int. J. Heat Mass Transfer. Vol. 25, No. 12, 1783–1812, 1982
Printed in Great Britain

0017-9310/82/121783-30 $03.00/0

HEAT TRANSFER—A REVIEW OF 1981 LITERATURE

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INTRODUCTION

This review surveys results that have been published in the open literature covering various fields of heat transfer during 1981. As in the past, the number of papers published during that period was such that only a selection can be included.

An Advanced Study Institute on "Low Reynolds Forced Convection in Channels and Bundles" was held at Ankara, Turkey, 13–24 July 1981. Nine sessions dealt with forced convection and heat exchanger technology. Proceedings of the institute will be published by Hemisphere Publishing Corporation, Washington, DC.

The 20th National Heat Transfer Conference was held at Milwaukee, Wisconsin, 2–5 August 1981, and was sponsored by the American Society of Mechanical Engineers and the American Institute of Chemical Engineers. Thirty-eight sessions were devoted to various fields of fundamental and applied heat transfer, including sessions on porous media and mathematical modeling. Invited lectures were presented by G. F. Hewitt on "Two-Phase Flow and its Applications: Past, Present, and Future" and by R. A. Seban on "Some Aspects of the Heat Transfer in Reflooding of a Single Tube". The Donald Q. Kern Award was presented to G. F. Hewitt and the Max Jakob Memorial Award to R. A. Seban. The papers presented at the conference are available as preprints or in the published series of the American Institute of Chemical Engineers. Many will also be published in the *Journal of Heat Transfer*.

The Third Symposium on Turbulent Shear Flows sponsored by the U.S. Air Force Office of Scientific Research, Research Offices of the U.S. Army and Navy, and the National Science Foundation took place on 9–11 September 1981 at the University of California, Davis. One of the sessions was devoted to heat and mass transfer in boundary layers and various papers in the other sessions touched on heat transfer. A bound symposium volume is available.

The International Centre for Heat and Mass Transfer organized a Summer School on "Heat Exchangers" (31 August–5 September 1981) and an International Seminar on "Advancement in Heat Exchangers" at Dubrovnik, Yugoslavia, 7–12 September 1981. The Summer School was organized around the Heat Exchange Design Book which is published by Hemisphere Publishing Corporation in five parts. Proceedings of the International Seminar are also available through Hemisphere Publishing Corporation.

The Second National Symposium on "Numerical Methods in Heat Transfer" was sponsored by the National Science Foundation, the Office of Naval Research, and the University of Maryland and was held at College Park, Maryland, 28–30 September 1981. Twelve sessions dealt with finite difference and finite element methods used in modeling heat transfer processes. A short course for engineers and scientists on "Computation of Heat Transfer and Fluid Flow" was held at the University of Minnesota, 16–19 November 1981.

The 102nd Winter Annual Meeting of the American Society of Mechanical Engineers, held 15–20 November 1981 at Washington, D.C., contained in its program sixteen sessions on fundamental and applied aspects of heat transfer. At the Heat Transfer Luncheon, Frank Kreith gave a lecture on the topic "Is There a Solar Future?". Heat Transfer Memorial Awards were given to A. Cezairliyan, Kwang-Tzu Yang and Ivan Catton. The papers presented at the conference are available as preprints or in book form at ASME Headquarters. Many of them will also be published in the *Journal of Heat Transfer*.

A considerable number of books dealing with heat transfer or including heat transfer topics have appeared on the market. They are listed in the bibliographic portion of this review. The *Latin American Journal of Heat and Mass Transfer* is published in Argentina with the Editorial Office at Avenida 1, No. 867, La Plata, Argentina.

The following highlights illuminate developments in heat transfer research during 1981:

In heat conduction, problems of phase change appear to be the main focus of published work. Solution methodologies, both numerical and analytical, also continue to evoke interest.

Complex passages, as they occur in compact heat exchangers, have been primarily investigated as channel flow configurations. Laminar and turbulent boundary layers are of continuing interest. Free jets and flow across cylinders have also found attention.

Heat transfer in porous media and in fluidized beds found much attention, probably since these processes are not completely understood as yet. They are investigated experimentally and analytically with models simplifying the process. Studies on one-phase heat transfer, as well as change of phase, and combined heat and mass transfer are reported in the literature.

Porous media were also considered in natural convection studies. Double diffusion processes were under investigation. External natural convection studies concentrated on flat plates in steady and transient state. Some of the articles included the effects of variable properties. Mixed convection over plates, cylinders, and spheres was the topic of several papers.

Processes in rotating flows have been studied which led to a significant increase in heat transfer or to a favorable ratio of heat transfer to pressure drop.

Heat transfer with change of phase remains an active research topic. As in past years, the majority of the papers in this category are nuclear reactor heat transfer oriented. Present papers in the reactor heat transfer subcategory discuss: bubble nucleation in a superheated liquid medium upon depressurization; boiling outside of sodium-heated tubes; heat transfer, CHF, and bubble growth when liquid coolant comes in contact with molten nuclear fuel; heat transfer in falling liquid films with rewetting and quenching; and boiling in a porous medium. Topics of papers on basic phenomena of boiling and condensing include: the details of bubble formation, growth and departure and the microconvection associated with these processes; the effects of surface coatings, e.g. gold or plasma-coated polymers; and the effects of surface preparations, e.g. nucleation pits. Several papers were presented on droplet evaporation in superheated vapor or in a noncondensible gas.

Interest is still strong in studying the performance of heat exchangers, whereas heat pipes have found little attention the past year.

The largest number of papers on solar energy continue to deal with the experimental and analytical evaluation of the performance of flat plate solar collectors. A significant number of publications describe the thermal performance of passive solar heat systems.

There is renewed interest in plasma heat transfer associated with new developments in high temperature plasma chemistry and plasma processing.

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

Problems of phase change appear to be the main focus of the published work in heat conduction. Solution methodologies, both numerical and analytical, also continue to evoke interest.

In a method for immobilizing moving boundaries in phase-change problems, a convection-like transport appears in the governing equations due to the coordinate transformation [22A]. By immobilizing the moving boundary, the 2-dim. freezing on the outside of a coolant-carrying tube was solved by a finite-difference method [57A]. A closed-form solution has been obtained for the 2-dim. freezing on a wall that is convectively cooled from the rear [21A]. A simple 1-dim. model, which neglects the details of axial variations, was employed to solve for melting about a horizontal tube through which a hot fluid passes [48A]. When a heat-generating liquid layer, insulated at the bottom, is cooled from above by contact with a cold environment maintained at a fixed subfreezing temperature, a frozen crust may be formed at the top. If the top cooling is not strong enough, the crust may grow and decay periodically [8A]. For melting about a horizontal cylinder, short-time solutions (i.e. small natural convection) were obtained by both an integral method and a quasi-steady model [69A].

In an analysis of unidirectional freezing of aqueous solutions during cooling at subzero temperatures, under conditions where the solute is completely rejected by the advancing ice front, the conventional diffusion equation is invalid [32A]. The enthalpy method has been reinterpreted to increase its accuracy [63A]. In a companion paper, a modification of the enthalpy method has been extended to cylindrical problems containing a circular cross section and spatially uniform boundary conditions [64A]. A similarity rule which greatly simplifies the solution of solidification problems has been extended to take account of the volume change that accompanies the phase change [51A]. A conformal transformation method was applied for the determination of the shape of the interface between a solidified layer formed on the inside of a cooled pipe of rectangular cross section and a warmer flowing liquid which passes along the axis of the pipe [60A]. The freezing of a liquid passing through a pipe with highly cooled walls may result in blockage of the pipe [47A]. Numerical solutions for 2-dim. solidification in a rectangular region have reaffirmed the importance of accounting for natural convection in the melt [45A].

A series solution of the Stefan problem with a convectively heated surface has been formulated and is purported to be exact [34A]. Series solutions have also been constructed for the Stefan problem with prescribed surface heat flux. A similarity solution is possible if the heat flux varies as $t^{-1/2}$ [61A]. The accuracy of approximate solutions for the uniform heat flux boundary condition has been assessed [9A]. In the Stefan problem, the magnitude of the Stefan number serves as a measure of the ratio of the sensible heat to the latent heat [53A]. The analysis for the freeze-coating of a continuous moving sheet differs from the standard Stefan problem in that the frozen layer thickness varies with the space coordinate along the moving sheet rather than with time [50A].

For calculating transient heat conduction in an expanding solid, the governing energy equation can be transformed to that for a fixed boundary problem [24A]. Highly nonlinear steady and quasi-steady conduction problems in simple geometries, including the effect of material travel, can be solved effectively by an iterative adaptation of the SEPELI fast elliptic equation solver [43A]. A finite element algorithm was used for the prediction of the rate of freezing of fresh water for various boundary conditions [23A]. A Heat-Balance-Integral solution for freezing about a circular cylinder was applied to soil systems [35A].

In an applications-oriented study, a model was developed for predicting the characteristics of an array of phase-change cylinders arranged in crossflow with respect to a transfer fluid [54A]. A design-oriented computation procedure for phase-change storage yielded the melted fraction and the shape of the liquid–solid interface [19A].

A number of experimental papers have dealt with freezing and melting. For freezing on a finned vertical tube, the heat transfer enhancement is proportional to the fin area when there is strong natural convection in the liquid melt [58A]. Experiments demonstrated that fins provided greater enhancement for melting than for freezing [4A]. When a cooled surface is placed in a superheated liquid, the freezing is initially strongly affected by natural convection, but as the superheat wanes, conduction in the frozen solid becomes the dominant heat transfer mechanism [59A]. Local and average heat transfer rates at the ice–water interface of an ice layer grown on a circular cylinder were determined directly from a photograph showing the shape of the ice layer [7A]. In the melting of the vertical surface of a solid by a heated liquid pool, the melt and the external fluid did not intermix along their mutual vertical interface despite the fact that the two media were miscible [15A]. In experiments on melting about a heated vertical cylinder, the measured heat transfer coefficients were little affected by whether the upper surface of the melt was subjected to a slip or no-slip velocity boundary condition [27A].

Solutions for a variety of steady state conduction problems have been published. In response to problems encountered in the cold-rolling of flat metal products, steady state temperature distributions were determined for a rotating roll subject to constant heat input over one portion of the circumference and convective cooling over another portion of the circumference [42A]. In another steady state problem involving complex boundary conditions, a solution was obtained for the temperature distribution in the wall of a tube which is in contact with the wall of a larger tube over part of its circumference [1A]. Numerical values of the conduction shape factor have been determined for multi-hole prismatic bars [39A]. A simple rule is presented for conduction shape factors for bodies with a geometrical axis of symmetry and with boundaries that are maintained at one of two uniform temperatures or are insulated [33A]. Conduction from surfaces to the 3-dim. surrounding space is relevant as a limiting case for natural and forced convection, respectively, as the Rayleigh and Reynolds numbers approach zero [10A]. To analyze heat conduction in spheres packed in an infinite regular cubical array, a unit cube with a sphere at the center was selected as the typical module [13A]. An analytical model for the computation of steady conduction across rectangular-celled enclosures is based on the assumption of quasi-1-dim. conduction in the cell partitions [14A]. Classical series methods are employed to solve steady conduction problems in r, z cylindrical coordinates for boundary conditions appropriate to nuclear reactor fuel pins [67A]. A wire heated by ohmic dissipation can, under certain conditions, have multiple steady states. The sufficient conditions for a unique steady state have been identified [40A].

Fins continue to evoke interest. Numerical solutions of the momentum equation for the fluid and the energy equations for the fluid and the solid yielded local heat transfer coefficients along the principal faces and the tips of an array of rectangular fins. The averaged tip coefficients were not markedly different from those of a segment of the principal face adjacent to the tip [56A]. In the presence of condensation on a rectangular fin, the optimum fin length is smaller than for the case of no condensation [29A]. The optimum efficiency for a cylindrical pin fin is higher than that for the longitudinal rectangular fin [55A]. The effect of a timewise periodic variation of the base temperature of a radiating fin is to increase the mean heat transfer rate [2A]. In a companion paper, the analysis is extended to temperature-dependent thermal conductivity and to spatially varying heat transfer coefficient [3A]. The standard assumption of a uniform fin heat transfer coefficient was lifted in favor of a linearly varying coefficient from base to tip [18A]. A technique for analyzing an array of extended surfaces is based on principles of graph theory, employing a novel kind of incidence matrix [52A].

Some interest persists in anisotropic materials, composites, and variable properties. By the use of a numerical mapping technique, steady state heat conduction solutions for anisotropic composites of arbitrary shape have been obtained [44A]. The finite integral transform technique has been generalized to solve transient heat conduction in a 3-dim. anisotropic medium [37A]. In determining the thermal conductivities of fibrous composites, an analytical model is employed whereby the fibers are considered to be uniformly dispersed in a matrix of resin [17A]. To deal with temperature-dependent thermal conductivity in 1-dim. transient conduction problems, it is proposed to replace the nonlinear heat equation with a linear version which contains a pseudo heat generation term [25A].

Aspects of contact have been investigated. The problem of the transient response of two semi-infinite solids not making perfect contact is treated by modeling the interface as a series of equally spaced strips making perfect contact, with the remaining area assumed to be perfectly insulating [46A]. If an elastic half plane is indented by a perfectly conducting rigid flat punch which is at a different temperature from the half plane, the nature of the contact depends on the magnitude and direction of the heat flow [11A]. The basic nature of the planar Hertz contact problem differs depending on whether heat flows into the material with the larger distortivity or vice versa [12A]. The finite integral transform technique was used to obtain a quasi-steady solution for two finite periodically contacting regions, with imperfect thermal contact at the interface [62A].

Various specific problems of transient conduction were solved. The solution for the transient temperature field in a sphere with single-sided heating modeled a problem in magnetic thermonuclear reactor engineering [66A]. Transient heat flow from a disk into a half-space when the disk temperature undergoes a step change was investigated by a separation of variables technique using oblate spheroidal coordinates [36A]. A series solution is presented for the transient temperature response of a semi-infinite cylinder to a step change in heat flux at a disk centered in the end face of the cylinder [5A]. In a related paper, large time solutions are obtained for a semi-infinite body heated over a circular region on its exposed face [6A]. In a transient technique for measuring thermal conductivity, the ramp function offers advantages over the step and Dirac functions [38A]. A correction for heat conduction between a sensor wire and its supports should be made to attain high accuracy [30A].

In addition to the solution methodologies described in the foregoing papers, several other methodology-related papers have been published. The advantages of using body-fitted coordinates as the basis for the numerical solution of heat conduction problems was illustrated by a range of examples [16A]. The unsteady surface element method is an approach for determining the temperature and heat flow at the interface between contacting, conducting solids [26A]. A finite element procedure for unsteady conduction has been developed which utilizes conjugate base functions and a modified form of the secant method for solving the discretized equations [49A]. The main advantage of the boundary element method for solving transient heat conduction problems is the reduction by one of the dimensionality of the problem [68A]. A numerical method for steady heat conduction, the iterative boundary integral method, is purported to have no limitations with regard to geometric complexity, type of boundary condition, or thermal conductivity [28A]. Using a conformal transformation which maps the region of interest onto the upper half plane, the Heat Balance Integral is generalized to 2-dim. transient heat conduction [70A].

For situations with moving temperature fields (e.g. metal forming, welding, plastic processing), moving finite elements were found to be advantageous as the basis of a numerical solution [41A]. An electrical analogue for solving conduction problems with moving heat sources on the surface yielded good agreement with solutions in Carslow and Jaeger [31A].

The inverse problem of transient heat conduction was shown to be ill-posed, as the solution exhibits unstable dependence on the given data functions [65A]. As a variant of the inverse problem, a method is described for predicting the geometry of a cavity situated beneath a surface whose temperature is known (for example, by infrared scanning) [20A].

CHANNEL FLOW

Experimental and theoretical work has been reported for the fluid flow and heat transfer processes in channels of both simple and complex geometry.

Among the studies associated with circular pipes, the heat transfer to liquid metals in laminar and turbulent flow has been dealt with [6B]. The situation with drag-reducing non-Newtonian fluids has been considered [41B]. Ref. [20B] deals with heat transfer to pseudoplastic fluids, while [7B] describes mass transfer to viscoelastic fluids. The dispersion from a line source in a turbulent flow is handled in [13B]. An analysis has been done for the unsteady heat transfer to power-law fluids [25B]. The effect of cross flow at the entrance on the heat transfer in tubes has been investigated [31B]. Ref. [15B] deals with ice formation in a pipe containing flows in transition and turbulent regimes. Mechanical heating of non-Newtonian fluids has been discussed [12B]. The gun barrel wall heat transfer has been analyzed [1B].

Ref. [35B] deals with the heat transfer in a capillary flow. Fluidized bed heat transfer to a single vertical tube has been discussed [8B]. Entry lengths for heat and mass transfer to power-law fluids have been determined [47B]. Ref. [46B] presents a simple solution for heat transfer to a power-law fluid flowing in a pipe. Convection velocities have been determined for a turbulent pipe flow [30B]. Simultaneous diffusion and convection in laminar tube flow has been studied [51B]. Ref. [32B] deals with heat transfer in profiled tubes.

Axial conduction in the fluid and the solid walls of the channel plays an important role in some cases. Axial conduction is included in the analysis of laminar flow in a circular tube [4B, 33B]. The conjugate convective heat transfer is considered for viscoplastic fluids [40B]. The flow in a circular tube is analyzed with the effect of axial conduction [48B, 49B].

A numerical solution has been obtained for the heat transfer between concentric vibrating cylinders [17B]. The flow and heat transfer in rectangular cavities has been solved by a numerical scheme [24B]. Ref. [9B] deals with 3-dim. laminar flow in ducts. The entrance region of a flat plate duct has been analyzed [37B]. An analysis is presented for flow and heat transfer in rod bundles [50B]. Heat transfer in a converging channel is considered [10B]. Ref. [21B] deals with multicomponent mass transfer in turbulent flow, Nucleation and bubble growth has been discussed for immiscible liquid composites [18B]. Laminar flow heat transfer in triangular passages has been investigated [38B].

Critical heat flux in horizontal channels has been experimentally measured [23B]. The response of a turbulent boundary layer to a sudden decrease in wall heat flux has been studied [45B]. Experimental data are reported for heat transfer at an upstream facing surface of an aperture [43B]. A numerical solution has been obtained for interrupted-plate passages with finite plate thickness [36B]. Experimentally determined heat transfer coefficients are given for a tube downstream of a cylindrical plenum [22B]. Friction factors in internally finned channels are analytically predicted [39B]. Ref. [2B] considers heat transfer in a channel at supercritical pressure.

An analysis has been reported for flow in twisted pipes [27B]; a related paper deals with heat transfer in the same situation [28B]. Turbulence models have been examined for ducts of annular cross section [26B]. Measurements are reported for the pressure drop in shrouded fin array with tip clearance [42B]. A study of flow and heat transfer in corrugated wall channels has been presented [19B]. Heat transfer is studied for a parallel-plate channel containing a cylinder [34B]. Ref. [3B] deals with heat transfer to pseudo-plastic fluids. The use of mass transfer method for heat transfer is discussed in [29B]. Experimental data for turbulized channels are correlated by the use of a turbulence model [14B]. The Rayleigh–Ritz method has been applied to forced convection [11B]. Laminar heat transfer in a duct has been considered with temperature-dependent properties [16B]. Ref. [5B] deals with the effect of mounting systems on heat transfer from inclined cylinders. The flow and heat transfer around a blockage in a duct have been considered [44B].

BOUNDARY LAYER AND EXTERNAL FLOWS

Most papers in the area of boundary layers are concerned with laminar and turbulent boundary layers on flat surfaces. Work has also been reported on turbulent jets, impingement flows, and flows over cylinders and spheres.

An integral method has been applied to the calculation of heat transfer in a turbulent incompressible boundary layer [32C]. The effect of a favorable pressure gradient on the heat transfer to a rough surface has been considered [6C]. A study is reported for effect of the Reynolds number on the turbulence structure of a slightly heated turbulent boundary layer [29C]. The combined free and forced convection on a vertical surface has been investigated [8C]. Boundary layers on turbine blades at different angles of attack have been studied [38C]. Ref. [23C] describes the shear stress and heat transfer characteristics at an infinite swept attachment line. The unsteady turbulent heat transfer from a flat plate has been investigated experimentally [12C] and numerically [13C]. The influence of adiabatic co-planar extension surfaces on the solar-collector heat transfer coefficients has been described [27C]. An experimental investigation of heat-stabilized laminar boundary layers in water has been reported [5C]. The influence of a density interface on a boundary layer has been discussed [21C]. A study has been reported on the forced convection near laminar separation [2C]. Laminar heat transfer has been investigated for the situation in which heat is transferred from a flat surface to a 2-dim. water jet [15C].

Among the studies related to free jets, the turbulent convective velocities in a plane jet have been measured [11C]. The structure of a slightly heated turbulent mixing layer has been studied [24C]. An experimental and theoretical investigation has been reported for a 2-dim. turbulent jet [14C]. An analysis of a laminar isothermal two-phase jet appears in [9C]. The interface heat transfer in a horizontal co-current stratified flow has been described [30C]. The complex flow and heat transfer phenomena arising from the impingement of a jet array with cross flow have been discussed [10C].

The flow and heat transfer at the axisymmetric stagnation region has been calculated [22C]. Experimentally determined heat transfer coefficients on a wall-attached cylinder are reported [28C]. Reference [1C] deals with the heat transfer in a tube bank. Laminar falling film characteristics have been determined for horizontal tubes [26C]. Heat transfer due to flow over rectangular bodies has been considered [31C]. Flow and heat transfer around a sphere has been discussed in a number of papers [18C, 35C, 34C, 7C].

Among studies concerned with time-dependent situations, a thermal boundary layer is considered [16C]. The temperature fluctuations in liquid-metal systems are analyzed [20C]. In a non-Newtonian flow, the unsteady thermal boundary layer is analyzed [25C]. Approximate convective heating equations have been proposed for hypersonic flows [37C].

Among the measurement and analysis of turbulence properties, the following topics have been investigated: decay of turbulence behind a grid [36C], turbulent scalar fields [17C], turbulent bursts leading to a prediction for turbulent Prandtl number [33C], origin of turbulence [4C], and transitional turbulent spot [3C]. The intrinsic scales in thermohydrogasdynamics have been identified [19C].

FLOW WITH SEPARATED REGIONS AND THROUGH POROUS MEDIA

Separated regions

Heat transfer was investigated from cylinders in unsteady flow [2D] and in high temperature surroundings [15D]. Experiments studied also heat transfer between a heated cylinder and an air stream with a water spray for steady and pulsating flow [3D]. An expression was derived [10D] for stagnation point heat transfer from a row of impinging jets to a concave cylinder surface. Similarity was verified for models scaled up by a factor of 10. A numerical 2-dim. analysis [6D] studied the flow and heat transfer in a rectangular cavity where the flow is starting from rest with some fluid entering at the upper left hand corner and leaving the cavity in the lower right hand corner.

Porous media

A numerical analysis [17D] studies the velocity and temperature field in a porous medium near an impermeable boundary. Flow and heat transfer are determined by three dimensionless parameters and the results reveal that errors occur when calculations are based on Darcy's law. Convection in a porous layer was also analyzed [5D] by integral relations at high Rayleigh number and for a fluid with temperature dependent viscosity. Mass transfer caused by natural convection in a porous medium consisting of packed spheres and screens was measured [7D] by the electrochemical method. The results were described by the following equation

$$Sh = 0.0228(Sc\,Gr)^{0.32}(R_h/d_p)^{0.22}$$

with d denoting the particle diameter and R_h the hydraulic radius of the flow cross section. Natural convection heat transfer was studied [4D] for a vertical impermeable partition between two porous media maintained at different temperatures. The results show that such a separation inserted in the middle of a porous slab reduces heat transfer drastically. Experiments on boiling heat transfer in porous wire mesh structures [14D] resulted in dimensionless expressions for the heat transfer coefficient.

Three papers deal with combined heat and moisture transfer in unsaturated porous media. The transfer processes in soil (loam and sand) surrounding a buried spherical heat source was studied [1D] analytically and experimentally. A rigorous solution describes the dynamic response of a porous medium or packed bed to an arbitrary varying inlet temperature using a two phase model [16D] and a steady state 1-dim. analysis [13D] considers condensation in a porous insulation occurring when the two surfaces are exposed to two different humid environments. Convective and diffusive transport as well as phase change are included.

Fluidized beds

Heat transfer to the particles of a fluidized bed is measured [11D] for the situation where small particles pass down through the bed of larger and heavier particles. Heat transfer is found to depend primarily on the particle residence time. An analysis of thermal dispersion and particle to fluid heat transfer [8D] considers small particles fluidized in the voids between larger stationary particles. Experiments on the maximum heat transfer coefficient between an electrically heated horizontal tube and a gas–solid fluidized bed with glass, dolomite, sand, silicon carbide, and alumina particles revealed that none of presently available correlations agree with the experimental results [9D]. New correlations are therefore proposed. Heat transfer between a fluidized bed of spherical and non-spherical particles with 2–3 mm size and immersed in-line and staggered bundles of horizontal tubes was measured at atmospheric temperature and pressure [19D]. Results were found to agree with Zabrodsky's theory for wide tube spacing. Heat transfer was also measured [18D] in fixed and fluidized beds through which a liquid is flowing. Mass and momentum transfer to Newtonian and non-Newtonian fluids (water and cellulose CMC solution) was measured in fixed and fluidized beds of uniform cylindrical pellets and spheres for Re from 0.038 to 6000 and Sc from 800 to 72 000 [12D].

NATURAL CONVECTION—INTERNAL FLOWS

Natural convection in enclosures continues to be of interest to many investigators. As has been true for some years, many papers relate either to convection in fluid layers heated from below or to flow in differentially-heated cavities that are generally heated on one vertical surface and cooled on another. This year there appears to be greater interest in heat transfer across shallow layers of fluid. The areas showing the largest increase in relative activity appear to be: (1) research concerned with thermohaline or double-diffusive convection, i.e. buoyancy forces due to differences in composition or concentration as well as variations in temperature; and (2) natural convection flow in porous media—many of these flows are of interest in geophysical phenomena as well as of importance to the fundamentals of fluid mechanics and heat transfer.

A number of studies considered special solutions for the flow and heat transfer in a horizontal layer heated from below. Boundary layer solutions are reported for non-linear thermal convection in a horizontal layer heated from below with stress free upper and lower boundaries [54F]. Steady numerical solutions in the form of 2-dim. rolls are found [15F] for convection in a low Prandtl number fluid; in a companion work [10F], an asymptotic model is described which agrees well with these numerical results. With poorly-conducting surfaces as the upper and lower boundaries, square cells are obtained as contrasted to the rolls found for conducting boundaries [50F]. Differences between buoyancy-driven and surface tension-driven stability in a horizontal layer has been studied in terms of the significance of the critical parameters [57F].

Other studies of buoyancy-driven flows in fluid layers heated from below include the influence of side-wall geometry. A numerical study of the post-stability flow pattern in a rectangular box has been presented [45F]. Growth rate calculations have been performed for flow in a cylindrical cavity [62F]. Measurements of the effect of temperature-dependent properties on low Rayleigh number thermal convection in a cylindrical cell show hystresis [73F]. Analysis on a fluid contained in a vertical cylinder with a free surface shows the relative importance of surface-tension-driven and buoyancy-driven phenomena [72F].

Experiments were reported on convection in a layer of a nematic liquid crystal which is heated from below [19F]. With this material there is a liquid–liquid phase change. A numerical study indicates the onset of thermal instability in a nematic liquid crystal heated from below [3F].

An analysis of convection in a Hele–Shaw cell shows that dissipation effects reduce the heat transfer [36F]. The effect of heat and mass transfer on Rayleigh–Taylor instability with a heavy fluid over a lighter one was analyzed [29F].

Many studies look at the natural convection from one surface completely enclosed within another with the fluid filling the space in between them. An example would be convection in the annulus between two cylinders maintained at different temperatures. A numerical analysis of the laminar convection between concentric and eccentric cylinders indicates an increase in Nusselt number when the center of the inner cylinder is below the center of the outer one [51F]. Electrochemical measurements are correlated by a power law variation of Sherwood number with Rayleigh number up to Rayleigh numbers greater than 10^{10} [60F]. Natural convection in the region between two concentric spheres was analyzed with a constant temperature or heat flux inner sphere boundary and with the outer sphere at variable temperature tending to give a stratified fluid layer [64F]. For an array of cylinders in a cubic enclosure, experiments indicate a higher heat transfer when the cylinders are horizontal as compared to when they are vertical [74F]. A procedure for fast numerical finite difference calculations has been developed and applied to predict the convection between spheres and cylinders [34F].

Several studies consider the natural convection in a vertical layer which is differentially heated by having one vertical wall at a different temperature from the opposite wall. Some numerical calculations of the heat transfer across vertical layers are said to be invalid outside a limited range of parameters due to points of instability [53F]. Other studies on differentially-heated vertical layers include constant heat flux boundary conditions [17F], non-uniform surface temperatures [20F] and the influence of Prandtl number over a large range of Rayleigh number [21F]. Extrapolation of finite-difference results for such flows can be made to zero grid size using only two different grid sizes [14F]. Experiments in vertical layers indicate single 2-dim. cells at low Rayleigh numbers and more complex flow at higher Rayleigh numbers [66F]. Calculations show the potential convection in the entrance region of a vertical concentric annulus [18F]. Transient convection in a vertical layer of water is analyzed to include the influence of maximum density point [56F].

Other studies of heat transfer in enclosures which are differentially heated on the sides, i.e. on the two vertical faces of a rectangular enclosure, include interferometric measurements in a shallow horizontal layer [61F], experiments up to high Rayleigh number [7F], and the effects of a vertical partition which partially obstructs the flow in a horizontal layer [43F]. A study on laminar high Rayleigh number convection in a shallow differentially heated layer found a power law variation of Nusselt number with Rayleigh number with the exponent decreasing with increasing Rayleigh number [63F]. Numerical calculations provide correlations for the heat transfer across a shallow rectangular cavity [33F]. Different solutions were obtained for the heat transfer across a shallow layer of low Prandtl number and high Prandtl number fluids [65F].

Using a thymol-blue technique, counterflow was observed in a horizontal cylinder connecting two fluid reservoirs maintained at different temperatures [9F]. An experimental and theoretical study considered the flow within a cavity extending from a reservoir [8F]. Penetration depth into an open cavity due to natural convection has been examined [2F]. An analytical and experimental study examined the flow in a shallow layer cooled from above with some fluid entering and leaving at one of the side boundaries [68F].

The natural convection in two separate chambers thermally connected by a wall of finite conductivity has been examined experimentally and analytically [71F]. Flow in an internal cavity connected thermally to a natural convection boundary layer on one of its outside walls has been examined [67F].

Natural convection has also been studied in inclined fluid layers. A power integral analysis [59F] indicates the parameters for instability and also shows the post-stability flow in both inclined and vertical layers. In an inclined plane air layer, the flow structure has been visualized over a range of inclinations and Rayleigh numbers [38F]. Analysis and experiments have been used in a study of the flow structure in an inclined annulus heated and cooled on its end plates [46F]. The influence of thermal resistance of wall boundaries on the onset of cellular convection in an inclined channel has been examined [23F].

Several studies consider double-diffusive convection in which the buoyancy forces that initiate and maintain the convection are due to both temperature variations and concentration variations in the fluid. A review [31F] of double-diffusive convection illustrates some important applications in astrophysics, engineering, and geology. An analysis of 2-dim. double-diffusive convection shows a transition between oscillatory and steady motion [16F]. An experimental study shows cell formation with a vertical concentration gradient when heated from the side [44F].

The criteria for stability of a thermohaline flow in horizontal layers of finite extent has been analyzed [48F]. Instability well below the Rayleigh number predicted by linear theories was found for thermo haline convection [52F]. The instability of salt-fingers in convection has been analyzed over a wide range of relative mass and thermal diffusivities [28F]. Under some conditions, three Rayleigh numbers are required to predict the stability of a rotating double-diffusive flow [47F].

As mentioned in the introduction, many papers report on natural convection in porous media. The 2-dim. convection pattern has been calculated in a region made up of two or three different layers heated from below [41F]. A general model for the stability of flow in a stratified porous layer has been proposed [55F]. The effect of geometry on critical Rayleigh number in convective modes for flow in an open fluid saturated box have been estimated [69F]. A finite element analysis predicts the flow in a porous layer heated differentially on the sides [25F]. A boundary layer analysis and experiments are compared for convection in a vertical porous layer differentially heated [40F]. The onset of flow as well as the preferred modes of flow in a permeable medium contained between vertical coaxial cylinders and heated from below have been calculated [4F].

Experiments on non-Darcy convection in a saturated porous medium show that earlier analyses overestimate the heat transfer rate [13F]. The importance of dissipation effects in such flows has been demonstrated analytically [12F].

Transient analyses have been performed for several geometries and boundary conditions with natural convection in a porous layer. An experimental and analytical study for a vertical layer heated differentially includes the effect of the difference in temperature between the liquid and solid [32F]. An analysis for individual localized heat sources has been generalized by superposition to get the effect of multiple heat sources [24F]. A simplified analysis of 3-dim. flow includes the influence of the heat transfer between the fluid and the solid matrix [11F]. The lateral motion of a flow into a saturated porous medium heated from one side has been analyzed [6F].

Analytical techniques have been developed to find the onset of thermohaline convection in a porous medium with properties varying significantly in the vertical direction [58F]. Other papers on double-diffusive convection in a porous medium include an analysis of the formation of the convecting layer [22F], and a study of the flow in a vertical layer heated from the side [35F].

Experiments on thermal convection in a differentially heated rotating annulus include the influence of a non-axisymmetric bottom surface [37F]. Depending on the input parameters, different flow regimes are observed in a rotating annulus with a variable bottom surface temperature [27F].

The transient and steady state flow in a toroidal thermosyphon heated from below and cooled from above has been examined including the influence of fluid addition [42F]. Experiments and analysis on the starting transient in an open loop heated from below and centrally has been examined [5F]. A study [76F] has considered the flow in a natural circulation system with parallel loops as might be used in the cooling of a light water nuclear reactor.

Several studies consider mixed convection (i.e. combined natural and convection) in ducts. The key parameter in correlating the bulk temperature rise with mixed convection in horizontal tubes is found to be the Rayleigh number raised to the 1/4th power divided by the Graetz number [26F]. An interferometer has been used to measure the mean temperature distribution along a horizontal isothermal tube with internal mixed convection [75F]. The effect of buoyancy on forced convection inside a vertical tube with radial internal fins has been analyzed numerically [49F]. Mixed convection in a square cavity in a channel wall with varying inclination has been examined [30F]. The flow pattern of mixed convection in a shrouded fin array depends on the relative temperatures of the fins and fluid surrounding them [1F].

The Galerkin method has been used to calculate natural convection in several arrays of vertical rod bundles [39F]. An orthogonal curvilinear coordinate system has been used for finite difference solutions of natural convection in non-rectangular enclosures [70F].

NATURAL CONVECTION—EXTERNAL FLOWS

Results of an experimental study of natural convection from a downward facing horizontal heated plate were reported and an explanation and correlation of the edge effects was made in terms of displacing the origin of a boundary layer solution [18FF]. The technique of live-fringe holographic interferometry has been used in an investigation of convective heat transfer beneath a heated horizontal plate in air [13FF]. Boundary layer flow of a thermomicroplar fluid past a non-isothermal vertical plate has been studied numerically [19FF]. For the class of natural convection flows on inclined surfaces in which inertial effects are unimportant (including flows at high Prandtl number) a local nonsimilarity analysis indicates that the effects of the surface-normal pressure gradient on the temperature profile can be characterized by a single local configuration parameter [25FF]. Two-dimensional buoyant clouds moving along inclined boundaries were investigated theoretically and experimentally and it was found that the "thermal theory" gives a good description of the flow in the slope angle range between approximately 5 and 90° [4FF]. A conjugate conduction–convection analysis has been made for a vertical plate fin which exchanges heat with its fluid environment by natural convection using a first-principles approach [29FF].

Transient natural convection adjacent to a vertical plate of finite thickness and heat capacity has been analyzed [26FF]. An investigation was conducted of the transient heat transfer from electrically heated conductors placed in cryogenic liquids [1FF].

Steady-state heat transfer from spheres and cylinders was the subject of several papers. A numerical analysis was carried out to describe the thick boundary layer around an isothermal sphere [14FF]. A study was made of steady state convection from a solid sphere to an incompressible Newtonian fluid with a Prandtl number of 0.72 for Grashhof numbers varying from 0.05 to 50 [15FF]. Numerical predictions of the flow patterns and heat transfer characteristics for laminar, steady-state, 2-dim. natural convection around a cylinder submerged in an unbounded Boussinesq fluid are in good agreement with previously obtained experimental data [12FF]. Experimental determinations were made of the heat transfer from circular cylinders as the cylinders were varied from horizontal to vertical [33FF]. A series solution method for laminar free convection boundary layer heat transfer over circular and elliptical cylinders has been extended to the treatment of nonisothermal objects [21FF]. In a study of the effects of vibrations on convection from horizontal cylinders, it was observed that for amplitude to diameter ratios exceeding 0.5, the relative vibrational heat-transfer coefficient increased almost linearly with the former irrespective of the frequency of vibration [10FF]. Experiments were performed to investigate the heat transfer characteristics of a short isothermal horizontal cylinder attached to an equi-temperature vertical plate and the Nusselt number was found to be rather insensitive to the cylinder length and the position of the cylinder along the plate [30FF]. Experiments were carried out on heat and mass transfer from air to horizontal tubes in the range 10^3–10^6 for $GrPr$ and $GrSc$ in order to investigate the analogy between heat and mass transfer and the effect of mass transfer on the mechanism of sensible heat transfer [11FF].

Experiments were performed to study the interactive natural convection from a pair of heated horizontal cylinders situated one above the other in a vertical plane [31FF]. Numerical solutions have been obtained for the upper-plate heat transfer response to a lateral offset of the plate from a position of precise alignment with a lower plate [32FF].

The temperature field of an axisymmetric laminar starting plume was measured for the first time using an interferometric measurement technique and Abel inversion data reduction [28FF]. The steady laminar plume above a horizontal laser beam, which is caused by absorption of thermal energy from the beam, was found to be 3-dim. [6FF]. An integral method was applied to the analysis of plume flow [17FF]. Round buoyant laminar and turbulent plumes in unstratified flow were analyzed [39FF]. The height to which dense vertical jets with two opposing buoyancy components rise was determined experimentally [34FF].

A study of the influences of property variations in natural convection from vertical surfaces showed that variable properties cause dramatic increases in heat transfer rates in the turbulent regime but have virtually no influence in the laminar regime [9FF]. A reference temperature method was developed by which heat transfer to fluids in the supercritical region under variable property conditions in laminar free convection on a vertical flat plate can be evaluated readily and accurately [16FF]. Plumes above line and point sources in pure and saline water have been analyzed, including the effects of nonlinear density variations [23FF]. A 2-dim. finite difference analysis has predicted the laminar flow and heat transfer characteristics for a vertical ice sheet at 0°C melting into fresh water by free convection under steady state conditions [37FF]. Time-exposure photographs are used to document the nature of the natural convection flow adjacent to a vertical ice surface melting in pure water at ambient water temperatures between 3.9 and 8.4°C [7FF].

The problem of mixed convection from a 2-dim. line heat source for both favorable and adverse buoyancy effects with respect to an oncoming vertical stream is analyzed in terms of two coordinate expansions, direct and inverse, valid for small and large streamwise distances from the heat source [2FF]. A buoyancy-extended version of the k–ε turbulence model is described which predicts well the main features of turbulent buoyant wall jets [22FF]. Experimental determinations were made of the local heat transfer rates of an electrically heated, vertical flat surface with combined free and forced convection of air in the same direction for the case of constant wall heat flux [3FF]. The cooling of a low-heat-resistance sheet that moves downwards at a velocity much smaller than the natural convection velocities that occur was analyzed [20FF]. The vortex instability of laminar, mixed-convection flow over an isothermal, horizontal flat-plate was investigated analytically using the linear stability theory [24FF]. The free-convection boundary layer along a partially heated infinitely long vertical cylinder disturbed by a steady horizontal flow was studied and the asymptotic solution indicates that the boundary layer is mainly induced by the buoyancy force near the thermal leading edge [38FF]. In a heat transfer and flow visualization investigation performed for a single cylinder and for single and double rows of cylinders submerged in an open channel flow, the regimes associated with free convection, combined convection and forced convection have been delineated [5FF]. In a pair of companion papers, nonlinear 2-dim. magneto-convection in a Boussinesq fluid has been studied in a series of numerical experiments both for the regime in which the development of nonlinear convection develops and for the dynamical regime that follows [35FF, 36FF]. Real-time holographic interferometry has been used to study the convective heat transport in a flat-plate solar collector [8FF]. Models of leaves and plants were used to study heat and mass transfer problems in agriculture, using an electrochemical technique [27FF].

CONVECTION FROM ROTATING SURFACES

Experiments and theory determined mass transfer to rotating disks and rings in laminar, transition, and developed turbulent flow [3G] on different portions of the surface. Measurements of heat transfer and friction loss in laminar radial flow through a stack of disks [4G] determined that centrifugal and Coriolis forces caused by rotation lead to a significant increase in heat transfer with simultaneous reduction in friction. The effect of impingement to increase heat transfer in condensation on a rotating disk was found [7G] to be larger experimentally than can be accounted for analytically. Naphthalene sublimation was used to measure mass transfer [2G] from a rotating inclined plate. The results revealed a tremendous increase in the transfer rate where the surface is exposed to wake flow. Computer results are presented [1G] for developing laminar free convection in an open ended vertical annulus with a rotating inner cylinder. The Prandtl number is 0.7, the radius ratio 0.5, one wall is isothermal and the other adiabatic. The Taylor stability problem was solved [5G] for a narrow gap between a hot rotating inner cylinder and a cool stationary one. The energy separation in vortex tubes can be increased [6G] when the tube is conical with a small opening angle. The length of the tube is also decreased.

COMBINED HEAT AND MASS TRANSFER

Combined heat and mass transfer is important in such diverse applications as cooling of high-temperature gas turbines, chemical processing, heat transfer in soils, and drying of paper. Many of the recent studies, motivated by a specific application, have even broader significance in terms of adding to our understanding of fluid mechanics and convective transport.

A numerical prediction of the film cooling effectiveness for discrete hole injection compares favorably with experimental results at low injection rates [2H]. The effects of heat transfer in porous layers as might occur on transpiration-cooled turbine blades has been analyzed; this work includes the effect of surface curvature [8H].

The influence of the injection normal to a surface on external mass transfer has been analyzed [3H]. The Nusselt number distribution along a channel with surface injection or suction has been calculated [13H].

A number of analyses consider transient heat and mass transfer where there is either a sudden or gradual change in a boundary condition such as wall temperature. The influence of blowing or suction on the heat transfer in the forward stagnation region of a body following a step change in wall temperature or heat flux has been examined [7H]. A finite difference analysis considers buoyancy-driven convection due to concentration and temperature variation on an isothermal vertical flat plate [10H]. An analysis considers the drying near a cylindrical heat source embedded in a moist porous media [5H]. Another study on transient convection combines analysis and measurements of coupled heat and mass transfer in an unsaturated porous media [4H]. The thickness of a frost layer on a cold surface over which a humid stream flows increases with time raised to the one-half power [12H].

Combined heat and mass transfer has been examined using laminar boundary layer analysis [6H]. A film model was developed to analyze coupled heat and mass transfer in multi-component systems [11H]. The relative importance of thermal diffusion and diffusion thermo effects have been examined for different boundary conditions of wall temperature and free stream concentration [1H].

The effects of finite propogation of disturbances using coupled wave equations of heat and mass transfer have been reported [9H].

CHANGE OF PHASE

Boiling

Nucleate boiling. A discussion of the applicability of the bubble flux density concept was discussed [35J] then extended for use with methanol. A low nucleation site density model for surface quenching was extended to high densities [40J] where the areas of influence of nucleation sites overlap. The enhancement of eddy transport in shearing two-phase flows by microconvention was demonstrated [80J]. An analytical and experimental investigation of bubble waiting time showed that bubble nucleation in subcooled flows contributes significantly to convection [5J]. Vapor bubble growth on a heated wall in a stagnant liquid was analyzed and a simple relationship between time and the diameter of a bubble at departure was found [22J]. Stroboscopic photography was used to determine instantaneous size and velocity of evaporating bubbles in sprays [45J]. Bubble growth rate data taken in various mixtures of liquids documented the effect of liquid mixture makeup [86J]. Further support of the Forester–Zuber growth rate law was found and a universal correlation was presented for developed boiling heat transfer on surfaces of known micro-geometry and on commercial heating surfaces [77J]. A photographic process was employed to create a regular array of pits in a copper surface [51J]; data from this surface showed enhancement of heat transfer and a significant effect on the boiling curve and burnout. The use of a gold film deposited on a glass substrate as a surface heater and resistance thermometer was demonstrated [59J]. Since the film was transparent, photographs could be taken from beneath. The evolution of enhanced surfaces was discussed [94J].

Forced convection boiling. A modification of an existing nucleate boiling correlation was proposed [81J]. The modification was the replacement of the bubble nucleation and growth term with one derived from natural convection nucleate boiling data. A previously formulated boiling heat transfer correlation for compact plate-fin heat exchangers was extended to include the effect of velocity [17J].

The results of a transition boiling study were summarized [63J]. Effects studied were: flow conditions; method of analysis; method of test operation, and equipment arrangement and construction.

A fully developed and adiabatic two-phase annular flow model with liquid entrainment was derived for flow in a pipe [47J]. A theory was presented for two-phase bubble flow in channels [68J]. An additional eddy diffusivity component was given for bubble agitation. The theoretical predictions of profiles of velocity and temperature as well as skin friction and heat transfer coefficient were compared to experimental data [69J].

Heat transfer measurements were made in the post-dryout region of an air–water dispersed flow [50J]. The effectiveness of wall-to-drop heat transfer depends mainly on the wall superheat for surface temperatures below the minimum film boiling temperature. The thermal entrance length exceeds that of single phase gas flow and decreases with increasing wall temperature. Turbulent droplet flow heat transfer was analyzed for the thermal entrance region of a tube [65J].

A model of the flow boiling crisis in high vapor quality annular flow was presented with some experimental results [73J]. Dryout measurements were made for the flow of boiling water in an annulus with various profiles of axial heat flux [11J]; for BWR geometries, total dryout power was only weakly dependent upon the profile shape. In [36J], previously published generalized CHF correlations were used to predict the well known relation between CHF and exit quality. A graphical method was used to present CHF data; three regimes were identified [37J]. These regimes were further discussed with respect to the flow patterns [38J]. A correlation of existing experimental data for CHF in uniformly heated rectangular channels was formulated [39J] and new experimental results with small heated length to diameter ratios were presented. CHF and liquid film flow rates were measured with upward flow in a uniformly heated tube [90J]. The exit film flow rate was found to be near zero at CHF conditions when the quality exceeded 50%. CHF in a helically-coiled tube was experimentally investigated [33J]; subcooled CHF decreases in the coil whereas high quality CHF is increased by coiling the tube. CHF experiments were performed in a LMFBR steam generator test facility [26J]; empirical correlations were presented. Dryout and pressure drop data were taken for helically coiled steam generator tubes [92J]. A criterion was developed to determine whether gravity influences burnout in upward flow or in downward flow over horizontal cylinders [29J]; low speed downflow runs indicated a buoyancy burnout mechanism that replaced the more common hydrodynamic burnout. A theory was given for the thermal-hydraulic phenomena, including dryout, during recovery of heated flow channels [84J]. The theory predicted the equivalent collapsed liquid level and the two-phase mixture level in a channel during certain nuclear reactor transients. A best-estimate prediction of transient CHF during reactor blowdown was presented [46J]. Several correlations based on local conditions were tested against recent blowdown heat transfer data.

A discussion of the spring model in superheated sodium boiling was given [27J] and density wave oscillations in once-through sodium-heated steam generator tubes were experimentally studied [91J].

Natural convection boiling. Transient boiling with various heater surfaces (wires and patches) and step power inputs was experimentally investigated [56J]; the onset of boiling was found to be time dependent. The variation of the local heat transfer coefficient around the circumference of a horizontal tube was found experimentally [12J]. Reynolds analogy was applied to film boiling on a horizontal plate and a heat transfer coefficient correlation was derived [42J].

Experimental and analytical studies of film boiling around small spheres [78J] were reported with a discussion of the relationship to vapor explosions. For subcooled liquid boiling, the ratio, not the difference, between the subcooled and saturated liquid film boiling Nusselt numbers is significant. Transient heat transfer from a horizontal cylinder initially in film boiling but responding to the passage of a shock wave was measured [31J] and analyzed [32J]. The transient heat transfer rate was as much as 20 times the steady state rate. The vapor mass is a key variable determining whether collapse is achieved. Implications for vapor explosions with liquid in contact with molten nuclear fuels were discussed.

An analysis was made of steady natural convection film boiling on a vertical plate in a porous medium [19J]; at a given Rayleigh number, the Nusselt number was found to be uniquely dependent upon the vapor film thickness. Contamination of nucleation sites by corrosion products was investigated [34J]. The effect of plasma-deposited polymers on nucleate boiling behavior of a copper surface was experimentally determined [30J]. A thin coating of TFE enhanced nucleate boiling while a thicker coating reduced it. A surface energy effect was postulated to explain this behavior.

Experimental results were presented for boiling of binary mixtures of varying compositions [23J]; bubble growth and shape change characteristics were as observed with pure liquids. The effects of heat flux, void ratio, and diameter ratio on boiling heat transfer in a concentric-tube open thermosyphon were examined [75J]; heat flux could be found as the summation of single phase free convection and boiling correlation values. Boiling of water drops superheated in a nonvolatile liquid [8J] is initiated at the water hydrocarbon interface by either growth of a single bubble or by streams of bubbles. The superposition of a magnetic field on boiling of mercury or mercury plus a wetting agent was shown to result in significant increase in the heat transfer coefficient [93J]. Increased field strength also lowered incipient boiling heat flux and encouraged transition to film boiling. Wave propagation of film or nucleate boiling over a heated surface was investigated analytically and experimentally [98J].

A new criterion of dryout was formulated for upward mist flow in tubes [49J]. An experimental investigation of CHF in horizontal channels with circumferentially varying heating [44J] showed that minimum CHF values with nonuniform heating were somewhat higher than those for uniformly heated channels. Measurements were made of CHF and rate of droplet entrainment when boiling a falling liquid film on the outside surface of a vertical tube [89J]; CHF was categorized according to film flow rate. CHF was measured in a countercurrent liquid vapor flow in a closed-end vertical tube [55J]. The length-to-diameter ratio of the test section was shown to influence the flooding CHF.

Condensation

Film condensation. A mixing length model was used to calculate velocity profiles and pressure drop in turbulent downward-directed flow with film evaporation or condensation [54J]. An experimental study of steam condensation on subcooled liquid film within an inclined duct [74J] showed that local heat transfer coefficients may be related to the turbulence intensity in the film. Verification was presented of multicomponent mass transfer models for condensation inside vertical tubes [95J]. Calculations for optimizing surface design were made of condensation rates on fluted surfaces [2J]. A numerical solution was found to wavy laminar film-wise condensation on vertical walls [79J]. Steady film condensation outside a wedge or cone embedded in a porous medium filled with dry saturated vapor was analyzed [18J]; a closed-form solution was found for Nusselt number as a function of Rayleigh number and film thickness. Methods were presented [71J] for determining suitable measures to prevent disturbances in heat exchangers due to periodic accumulation of condensate on tubes. Laminar film condensation of binary vapor mixtures was analyzed revealing some interface characteristics and showing the effect of linearly varying the wall temperature [72J].

Condensation rate and vapor and condenser surface temperature measurements were made during film condensation of mercury on vertical, nickel-plated, copper surfaces [58J]. Experimental heat transfer and hydrodynamic results in film condensation on vertical surfaces [25J] indicated the effects of the strength, frequency and uniformity of an electric field.

Gold surfaces were experimentally shown to promote dropwise condensation of steam [96J].

Free condensation. The validity of the basic assumptions of dropwise condensation was assessed [67J]. Results of an experimental study of surface characteristic and material property effects on dropwise condensation were presented [1J] and, in a technical note [85J], a discussion was presented on the effect of Knudson number on dropwise condensation. An analysis was made for the stagnation region of a spherical water drop moving in an environment composed of particulates and a saturated mixture of the following gases: condensable steam, noncondensable and nonabsorbable air, noncondensable but absorbable elemental iodine, and chemically reactive methyl iodide [20J]. Numerical analyses were made of (1) condensation of multicomponent vapor in the presence of inert components [9J] and (2) laminar condensation near the stagnation point of a droplet moving in a saturated mixture of steam, air and a noncondensable but absorbable gas [21J].

Vaporization

Vaporization of films. The system mean void fraction model was applied to problems involving incomplete vaporization [55J] and an analysis was made of the phenomenon of hydraulically-controlled dryout in a vertical channel [83J]. An analysis of laminar mist flow along a flat plate [87J] showed that the high heat flux resulted from a superposition of film evaporation and convective heat transfer. Data was taken on evaporating films on the inner wall of horizontal tubes [41J]; spiral grooves can double the evaporation heat transfer coefficient due to the capillary phenomenon. Local heat transfer coefficients were determined for evaporation of trickle films on vertical surfaces [70J]. A model of particle bed dryout based on the phenomenon of flooding [60J] predicted a dryout heat flux that depends on the square root of the particle diameter. Enhancement of evaporation initiated by the differential vapor recoil mechanism was experimentally studied [62J].

Experiments on refilling and rewetting hot horizontal tubes [14J] indicated that gravitational effects are important and lead to flow stratification; an analysis followed [15J]. A similar experiment [16J] showed a liquid tongue running along and rewetting the bottom surface; the phenomenon was thought to be hydrodynamically controlled. Quenching data were presented for reflooding of zircaloy and stainless steel clad rod bundles with cold water [64J] showing that zircaloy quenches faster under similar conditions.

Free vaporization. A numerical solution was presented [66J] for evaporation in a spray evaporator; a reflooding index is related exponentially to the droplet diameter and wetting ratio. Turbulent droplet flow heat transfer under post-dryout conditions was numerically analyzed [97J]; the droplets were distributed heat sinks and the eddy diffusivity function of Deissler was used for the vapor phase. An analytical study of both diffusion-controlled and radiation-controlled evaporation of a spray [6J] demonstrated that evaporation characteristics were correlated best by the droplet initial Sauter number. An analysis was presented for water evaporating in high temperature air [28J]. Experiments with liquid droplets evaporating into a flow of gas capable of condensing [43J] showed some surface condensation of the ambient gas and indicated that the process was limited by heat and mass transfer. An augmentation of evaporative cooling of liquid drops falling freely was attempted by coating the drops with an immiscible, volatile liquid [53J]; the dependence on initial drop temperature, volume ratio of volatile liquid to the drop liquid (water) and the air temperature and humidity was investigated. An analysis was made of unsteady evaporation and condensation heat and mass transfer in a single drop [64J] and an experiment was made of condensation or evaporation of a volatile liquid drop or condensible gas bubble in a liquid medium [82J]. An approximate 3-dim. numerical model for predicting characteristics of spray units was presented [61J] that predicted local distributions of dry-bulb temperature, absolute humidity and air streamlines within the flow.

An analysis of bubble growth during depressurization of liquid was made [13J] and a method for correlating the extent that the pressure undershoots the saturation pressure was given [3J]. The limit of homogeneous nucleation under these conditions was shown to lie close to the liquid spinodal line [48J]. The limits of superheat of some binary mixtures were measured at high pressure [7J] and a model was devised; the results apply to the burning of droplets of fuel blends which are mixtures of volatile and nonvolatile liquids. An analysis of thermal, mass and dynamic interaction between a vapor–gas bubble and a liquid during a rapid pressure change or within a sound field was presented [57J].

Other

Experiments were made for mass transfer to air bubbles adhering to the inside wall of a tube carrying supersaturated liquid [4J]. The effects of mass, momentum and thermal variations on the dynamics of inert gas bubbles moving in a channel flow of a liquid and dissolved gas solution were analyzed [52J]; differing axial distributions of pressure and temperature were presumed. A method was suggested [88J] for determining mass transfer coefficients at liquid–liquid interfaces. An analysis was made of the thermocapillary migration of a fluid droplet inside a drop assuming space laboratory environment [76J].

RADIATION

Radiation in participating media

Radiative transport in emitting, absorbing, and scattering media is of continuing interest. The basic theory for radiation transfer in an arbitrary medium has been derived using the general form of the Bethe–Salpeter equation [4K]. Time-dependent radiative transfer is studied in a semi-infinite medium with a reflecting boundary [8K]. The accuracy of an approximate method for calculating the intensity and fluxes of radiation from an inhomogeneous two-phase layer with emitting and reflecting boundaries has been ascertained for a wide range of initial parameters [1K]. Studies are reported of infrared (10 μm) induced evaporation of large water droplets [15K].

Considering gas enclosures the geometric-mean transmittance and total absorptance between two finite areas can be reduced to single numerical integrations, thus eliminating much of the mathematical complexity [18K]. A new type of spectrometer has been developed for performing rocket measurements of the near infrared absorption spectrum of the upper atmosphere [11K]. It is shown that all gaseous admixtures in a radiation-absorbing non-equilibrium gas may be induced to drift along the light beam. This effect may be useful for separating sulphur isotopes [9K].

Results of an analysis of radiative–convective heat transfer of an axisymmetric blunt body in hypersonic air flow are presented for ablating graphite surfaces [13K]. An analysis of radiative transfer in a plane slab takes an azimuthal dependence of the radiation field into account, a situation which is of significant practical importance [16K].

Simple solutions for the effective thermal conductivity for combined radiation and free convection in an optically thick heated fluid layer compare favorably with numerical solutions of the governing energy equation incorporating both turbulent heat transport and thermal radiation [5K]. Considering turbulent flow of a multiphase medium with absorbing, emitting and anisotropically scattering particulates bounded by a heated or cooled constant-temperature wall, numerical results are presented for a wide range of the governing parameters [3K].

A study of the radiative heat flux in absorbing, emitting and linear anisotropically scattering cylindrical media shows that in engineering applications approximate methods may be used to accurately model the radiative contribution to overall heat transfer rates [2K]. Analytical studies of multidimensional, radiative transfer with anisotropic scattering are in satisfactory agreement with corresponding experiments [10K].

A new gray-gas approximation for carbon dioxide standard emissivity provides simplicity and reasonable accuracy (errors $<6\%$) for temperatures between 800 and 1800 K and for $1 \leqslant pL \leqslant 10^3$ cm atm [6K]. An experimental investigation of thermal radiation of certain gaseous hydrocarbons reveals that the emissivity is strongly dependent on the number of carbon atoms in a molecule [17K].

The $P-1$ approximation has been generalized for non-gray problems offering the advantage that all solutions can be expressed in terms of the spectral absorption coefficient. It is shown that this technique is superior for gases [19K]. The radial heat flux and its divergence are determined both exactly and approximately for homogeneous suspensions of small particles in an isothermal cylindrical medium. A closed-form approximate solution for the surface heat flux is in excellent agreement with exact results [7K].

Infrared measurements of the stratospheric composition indicate that measured NO and NO_2 concentrations are in disagreement with absolute values predicted by the Oxford 2-dim. diurnal model, but in close agreement with their day-time changes

[14K]. By using a new non-steady measuring method, the different radiation fluxes, as well as the net radiation fluxes, can be established for rivers [12K].

Surface radiation

The calculation of shape factors for radiative transfer has been extended to rectangular, plane surfaces of arbitrary position and size. A computer facilitates a fast evaluation of the derived equations [2L]. Effective emissivities of conical cavities having diffuse surfaces are computed by an iterative procedure and effective reflectances are determined with a series technique which involves powers of the reflectance of the wall material [3L].

A perturbation analysis for periodic heat transfer from radiating fins shows that within the range of parameters of this study, the net effect is to decrease the mean temperature and increase the mean heat transfer rate [1L]. A technique for measuring reflectance factors under diurnal and intermittent cloud insolation conditions using hand-held radiometers has been developed. The results of such measurements indicate that this technique may be useful for achieving uniform reflectance factors for remote sensing studies [4L].

MHD

There is a continuing interest in MHD and its applications. In particular, MHD generators are considered.

Because of the high temperatures and the large sizes of large scale MHD generators, radiative heat transfer in the combustion gases becomes a significant energy transport mechanism [8M]. Studies of heat and mass transfer in MHD channels indicate that heat transfer by gas radiation almost equals that by convection for smooth walls, and amounts to 3/4 as much as the convective heat transfer for rough walls [3M]. A combined convection–gas radiation, two-zone flow model is formulated for studying heat transfer characteristics of MHD radiant boilers [4M]. Studies of combined conduction, convection, gas radiation and particle radiation in a reference MHD diffuser (1700 MW thermal) show that heat transfer by convection amounts to 25 MW and radiative heat transfer from 44 to 79 MW depending on the rate of ash carryover into the channel [2M].

The results of an analysis of a fully developed forced and free convective MHD flow between two electrically conducting vertical plates indicate that an increase of the thermal conductance ratio of the two plates leads to both an increase of the velocity and of the temperature [7M]. For establishing heat transfer scaling laws for MHD channels and diffusers, a quasi-3-dim. model has been developed for determining convective and radiative heat transfer characteristics [1M].

Open-cycle MHD generator channel development is discussed with emphasis on critical design criteria and limitations on channel operating parameters [6M]. The development of steam generator components for open-cycle MHD power plants requires, for example, the design of radiant furnaces [5M]. Results of performance studies are reported for a multiphase boiling MHD generator [9M].

NUMERICAL METHODS

Papers reporting the use of numerical methods for solving specific physical problems are listed in the appropriate category pertaining to the problem. Occasionally, some numerical innovations are embedded in such papers. The literature cited in this section is primarily aimed at the development of a numerical method rather than its application.

The inverse heat conduction problem has been treated [1N, 17N]. A calculation scheme for transient phase change around a cylinder is given [18N]. Variable time step methods for the Stefan problem have been examined [10N]. Ref. [4N] describes an efficient technique for calculating two-dimensional temperature distributions. Turbulent temperature fluctuations in liquid metals have been numerically simulated [8N]. A Monte Carlo technique has been adapted for the determination of radiation interception [16N]. An implicit Eulerian method has been used for steam generator analysis [5N]. Transient conjugate problems have been treated by a quasi-steady approach [15N]. Singular perturbation techniques using finite elements have been developed for 1-dim. [6N] and 2-dim. [7N] convection–diffusion problems. Ref. [12N] describes a generalized finite-difference method for heat transfer problems in irregular geometries. A general calculation procedure for 2-dim. fluid flow and heat transfer has been described [11N]. The finite analytic method has been used for the heat transfer in a cavity [3N].

A method has been developed for the solution of nonlinear boundary-layer equations [14N]. The concept of group transformations has been applied to the nonlinear heat diffusion equation [9N]. The technique of computer-extended series is developed in the context of natural convection [13N]. A variational approach has been employed in the prediction of laminar flow with dissipation [12N].

HEAT TRANSFER APPLICATIONS

Heat exchangers and heat pipes

A new method for the prediction of heat transfer coefficients is presented [1Q] in gas flow normal to banks of finned and smooth tubes with triangular pitch. A new design [14Q] of a shell and tube heat exchanger resulted in a slight increase in heat transfer coefficients with a significant reduction in pressure loss. Tests on pilot plants [6Q] revealed that measured heat transfer coefficients and pressure drops for air coolers do not satisfy available correlations for a small number of rows or forced draft. Experiments [2Q] studied the influence of fouling biofilms on heat transfer under controlled conditions. Results compare well with those of a simple mathematical model.

Several papers are concerned with the performance evaluation criteria of heat exchangers. Previous work by Bergles and Webb was extended to establish such criteria for single phase flow in tubes including the effect of shell side enhancement and fouling [19Q]. It was also investigated [13Q] under what conditions such criteria remain unchanged when the two fluid streams are switched. Some fundamental relations were developed [12Q] to describe the performance of a tubular heat exchanger based on *NTU*, heat capacity ratio, and a temperature efficiency parameter. A method of stochastic approximation [16Q] to identify parameters of parallel flow heat exchangers compares favorably with unsteady experimental results.

A study [9Q] concludes that tiny fins result in the best surface geometry for vertical condenser tubes with outside condensing surfaces. The design of multizone condensers for desuperheating, condensing, and subcooling is discussed [11Q]. A rotary dry cooling tower was developed [17Q] with disks rotating between a hot water bath and a forced air stream. A layer of oil on top of the water eliminates evaporation. An analysis was verified by experiments. The prediction of boiling heat transfer is discussed [5Q] for a compact plate-fin heat exchanger with frequent interruptions. In this extension of a previous study the assumption is made that local heat transfer coefficients are related to local metal-to-liquid temperature difference.

A parametric study [8Q] of a particulate direct contact heat exchanger shows that heat exchange improves as the particle diameter decreases, the heat capacity ratio, the flow rate ratio, and the approach temperature increase for laminar bulk flow and particle Reynolds numbers from 20 to 500. Experiments on heat transfer in tubeless evaporators [15Q] are compared with a theory assuming that uniformly distributed drops heat up and evaporate.

Three papers deal with the thermal performance of regenerators. Addition of 15% steam to combustion air doubled the heat transfer coefficients during the cooling period and increases them by 15% during the heating period [3Q]. It is demonstrated [7Q] how latitudinal conduction can be incorporated in lumped heat transfer coefficients for thermal regenerators. A theoretical model and experiments of heat and mass transfer in rotary regenerators with condensation, evaporation, and convection are described [18Q] and results obtained with an experimental facility are presented.

Two papers are concerned with heat pipes. From an experimental study of the transfer mechanism in the evaporator [10Q] it is concluded that the heat transfer mechanism in a wick of screens is identical to that in a sintered powder wick. Heat pipes filled with sodium reduced the wall temperature at the stagnation line of a space shuttle wing from 1500 to 900 K [4Q].

General

Experiments [13S] on water vapor contribution to the erosion of steel in high temperature flows are reported and interpreted by a surface reaction model. A theory is proposed [9S] to describe the effect of nozzle erosion on heat transfer in a ladle of molten steel during pouring. The nozzle temperature is calculated and compared with plant observation. Experiments established [14S] that the lowest temperature on a surface cooled by a liquid spray is a linear function of the spray mass flux. The vertical temperature distribution is calculated [2S] in a storage tank fed at its top with warm fluid in laminar flow.

Different designs of air cooled gas turbine blades have been discussed [10S]. Five computer programs used to calculate heat transfer rates to gas turbine blades have been compared with experiments [8S] at the University of Oxford free piston wind tunnel. The programs differ by their turbulence models. All calculated results show the right trend but quantitatively they differ considerably. An equation $Nu = cRe^n$ is developed [16S] from literature data describing average heat transfer coefficients to turbine blades. An analysis [6S] simulates the disturbance of a combustion chamber with film cooling by air jets with a model replacing the jets by cylinders normal to the chamber wall. The results are compared with experiments. Model tests determining heat transfer in the casings of turbines with a loop system of steam flow have been performed [22S] and the results are recommended for use in the design of similar casings.

An experimental and analytical study [7S] points to the conclusion that instantaneous heat transfer in an engine exhaust port is primarily caused by jet induced fluid motion.

The process in a liquid metal fast breeder reactor under natural circulation is simulated dynamically by a computer code [4S] using specifications for the Clinch River Breeder Reactor Plant. The results of experiments are reported [5S] for a circulating fluidized bed with coal combustion. A mathematical model of heat transfer from a large enclosed flame in a rotary kiln [15S] predicts the gas and refractory temperature profiles. It is based on the Hottel–Sarofim method and tested against experimental results.

Experiments on the cooling of high pressure rocket thrust chambers with liquid oxygen [20S] verified a supercritical heat transfer correlation developed from heated tube experiments. Design and off-design performance calculations of space radiators with liquid coolant circulation and radiating to the surroundings have been performed [12S] with and without heat pipes. An analysis shows [3S] that conventional methods do not describe adequately the unsteady convective heat transfer in a gun barrel.

A three-parameter equation is developed [18S] with the parameters *Re*, *Pr*, and $K = \varepsilon U/L$, using the improved equation

$$\tau = q\left[1+\varepsilon\left(\frac{du}{dt}\right)^n - 1\right]$$

for the shear. Velocity and temperature boundary layers are calculated with this equation. Frictionally generated heat in a polymer may lead to a heat explosion [19S] when this heat is not balanced by heat transfer to the surrounding. A model is proposed [11S] for the analysis of heat and mass transfer in hydroscopic capillary extruded products using equations for the liquid and vapor fluxes depending on temperature and equilibrium moisture content gradients.

An analysis [1S] of heat transfer during cooling of spherical food products establishes the parameter range for best effectiveness when the air passing over the product is continually wetted by a chilled water spray. The temperature separation in a Hartmann–Sprenger tube can be improved [17S] by coupling it to a resonator and by use of a nozzle with a thin rod along its axis. The cost of large scale heat transfer research and testing makes it necessary to carefully optimize the test program [21S].

Solar energy

Topics of major interest among the heat-transfer related solar energy publications include: solar radiation, flat-plate and concentrating collectors, thermal storage and system performance, both passive and active. The standard technique of analyzing solar photometer data to determine atmospheric optical depth and the spectral solar constant inadvertently weight the data unequally [10T]. Seasonal variations of atmospheric clearness numbers for use in clear day solar radiation modelling are proposed [9T].

Two analyses of a non-linear flat-plate collector are presented in which the overall loss coefficient is assumed to be a linear function of the temperature difference between the fluid in the collector and the environment [5T, 7T]. A brief analysis re-examines the original justification for linear and second-order efficiency characteristics [6T]. Simple stagnation-condition measurements for solar collectors can provide a direct measurement of the temperature dependence of the heat loss coefficient [8T]. Based on available correlations, relations were found for the local maxima's and minima's in heat transfer as the gap spacing is varied in flat-plate solar collectors [15T]. A simplified equation was proposed for evaluating the top loss coefficient for a flat-plate solar collector [2T]. New expressions for the heat transfer factor F_R based on inlet, outlet and mean fluid temperatures were derived for use with the Hottel–Whillier collector model by the use of restrictive heat transfer assumptions [14T]. The thermal boundary layer problems associated with flat-plate solar collectors have been analyzed using fourth degree polynomials [17T]. A fluorocarbon loaded solar collector system was found to have efficiencies as high as 83% for a collector-to-ambient temperature difference of approximately 10°C [23T]. Experimental thermal efficiencies for a distributed flow, subatmospheric pressure, flat-plate solar collector were reported for a wide range of environmental and operational conditions [24T]. New experimental results make it possible to draw more general conclusions about the effect of tilt and end clearance on the performance of honeycomb in suppressing convection in flat-plate collectors [30T]. The number of slabs and their thicknesses are both important parameters in the performance of thermal trap collectors [22T]. The energy absorbed by a fluid confined within a circular-cylindrical cover was calculated [26T].

The intermediate range of concentration ratios which can be achieved with compound parabolic concentrators (CPC) without diurnal tracking provides both economic and thermal advantages for solar collector design even when used with non-evacuated absorbers [21T]. Mathematical formulations were developed to study thermal processes in a CPC collector fitted with a concentric, evacuated double pipe to serve as a heat absorber [11T].

Stratification effects in a rock bed storage unit were analyzed in terms of a stratification coefficients which is shown to be a system constant that depends only on three dimensionless system parameters [20T]. Significant reductions in the collector area requirements for a particular system performance can be realized by employing seasonal sensible storage [3T]. The characteristic variation of the rate of heat transfer to and from a latent heat thermal energy storage capsule was investigated analytically and experimentally [12T]. The addition of phase change thermal storage for buffering will substantially improve the performance of parabolic dish solar thermal power plants [16T].

A design method for direct gain passive solar heating systems is given which is more general than the "Solar Load Ratio" method [18T]. The effect of air flow rate in collector-storage walls was analyzed [29T]. A heat transfer model of a parallelepiped tank full of water and covered with a translucent insulation of diffuse material to solar energy, was developed considering the multiple absorptions and reflections to evaluate the heat gain or loss by the water [27T]. A passive energy collection and storage system for greenhouses, based on the collection of energy from the greenhouse atmosphere and storage in the ground, is investigated [19T].

A simple periodic analysis of a basin-type solar still (both single as well as double) quite satisfactorily explains the thermal performance [25T]. Precipitation in a 'saturated' solar pond can increase the reflectance of the bottom of the pond and this can reduce the width of the nonconvective zone and, thus, seriously degrade the performance of the pond [13T]. A new technique was devised to make quantitative estimates of the value of the three major components of a solar-driven chemical heat pump [28T]. A second law efficiency analysis for solar water heaters was presented [1T]. Mounting heat-sink fins in a suitable funnel can contribute substantially to their effectiveness in cooling solar energy converters [4T].

PLASMA HEAT TRANSFER

There is a continuing, strong interest in plasma heat transfer. A 2-dim. analysis of free convection in horizontal, high pressure arcs consisting primarily of Hg vapor confined in quartz tubes, shows that the vertical location of the hot core is in good agreement with experimental findings [12U]. Similarity relations derived for electric arcs in forced axial flow indicate that a turbulent flow model is more consistent with experiments than a laminar flow model [16U]. Results of a two-temperature modeling of the anode contraction region of a high intensity argon arc indicate that the temperature discrepancy between electrons and heavy particles is very pronounced in the arc fringes and the region close to the anode [3U]. A similar study of an arc plasma reactor indicates that enhanced Joule heating in the constricted arc path raises the electron, as well as the heavy-particle temperatures resisting the penetration of the cold gas into the hot arc core [2U]. Calculations of the heating mechanism of cathode craters in vacuum arcs show that Joule heating is insufficient to explain the short time scale of their formation. Therefore, ion impact heating is considered to be the dominant process [9U]. A sectioned, rotating cylinder of 10 cm diameter is used for measuring local heat fluxes and current densities at the anode of a stabilized, rotationally symmetric atmospheric pressure argon arc for currents from 100 to 500 A. The results indicate maximum current densities of 340 A cm^{-2} and heat fluxes up to 7 kW cm^{-2} for the 500 A arc [1U].

The reduction and dephosphorization of molten iron oxide with hydrogen–argon plasmas shows that the efficiency of hydrogen utilization for the reduction is much higher than predicted by equilibrium values below 3000 K [14U]. Transition metal nitrides and alloys may be directly synthesized in a DC argon–nitrogen plasma from powders of the corresponding metals [17U]. Superconducting compounds such as cubic $\alpha-MoC_{1-x}$, etc. which are metastable at room temperature have been formed by heating and quenching of the corresponding equilibrium phases in a plasma jet [11U]. A reactive plasma zone melting process has been used for the purification of metallurgical grade silicon [13U]. Investigations of the heating of submicron particles (metals) in a thermal, optically thick plasma indicate that kinetic methods are required for calculating heating of the particles [18U]. A 100 kW three-phase plasma furnace has been used for spheroidization of aluminum silicate particles. A simple, 1-dim. model for particle heat transfer explains the maximum processing rates and the detrimental effect of an inhomogeneous particle size distribution [7U]. A new sample injection method, incorporated into the design of a r.f. plasma torch, is capable of complete evaporation of refractory materials at high feeding rates without interfering with the stability of the plasma [21U].

Transport properties of hydrogen, oxygen, and argon mixtures are calculated for a temperature range from 4000 up to 10 000 K using the Chapman–Enskog approach [15U]. Studies of the total emission coefficient of an air plasma at temperatures from 17 000 to 20 000 K and pressures from 3 to 15 MPa indicate that calculated data in the literature are 2–4 times too high [6U].

Studies of the behavior of cold Langmuir probes immersed into a moving, compressible, high pressure plasma (MHD plasma) take the cooling-induced reduction of the local ion mobility and the distortion of the hydrodynamic flow pattern close to the probe into account [4U]. By measuring heat transfer rates from a rarefied argon plasma to a biased tungsten wire, accommodation coefficients of argon atoms were found to be 0.62 and for argon ions a value of 0.48 has been found [8U]. A new numerical method has been developed for determining local emission coefficients in asymmetric plasmas (extension of conventional Abel inversion) [20U]. Results of laser-induced fluorescence measurements in high-pressure mercury, mercury–metal halide, and sodium–mercury arcs indicate that this method offers interesting possibilities for the determination of local particle density ratios, local spectral line shifts (Stark shifts) and transition probabilities [19U].

The heat flux along a uniform magnetic field due to a temperature gradient is calculated using a Monte-Carlo solution to the Fokker–Planck equation. The calculated heat flux makes a smooth transition between the analytic expressions for the short and long mean-free-path limits [10U]. Small scale features (10–20 μm) in laser-produced plasmas may be influenced by an instability associated with the density dependence of radiative energy losses [5U].

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