CHEMICAL ENGINEERING PROGRESS SYMPOSIUM SERIES ABSTRACTS

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The *A. I. Ch. E. Journal* will publish, from time to time, abstracts of the articles appearing in the Symposium Series volumes. Recently published volumes are abstracted below.

HEAT TRANSFER—STORRS, Vol. 56, No. 30, 1960.

Fluid Mechanics and Heat Transfer in Vertical Falling-Film Systems, A. E. Dukler. New equations are developed for velocity and temperature distribution in thin vertical films. The geometry is similar to that found in falling-film evaporators, vertical condensers, and film-cooling equipment. These equations utilize the expression proposed by Deissler for the eddy viscosity and eddy thermal conductivity near a solid boundary, thus introducing turbulent fluctuations close to the wall. The differential equations are solved numerically with an IBM-650 computer. From the velocity and temperature distributions, liquid film thickness and point heat transfer coefficient are calculated. Results, which are presented graphically, include laminar and turbulent flow conditions and account for different liquid properties and the presence of concurrent (or countercurrent) gas flow. From the point coefficient data, average condensing heat transfer coefficients are developed. Results are shown to agree with the classical Nusselt relationships at low Reynolds numbers and no interfacial shear. In the turbulent region agreement is obtained with the empirical relationships of Colburn for fully developed turbulent flow in the absence of interfacial shear and with recent experimental data at high pressure drops. These results now provide reliable values in the commercially important region between these two extremes. Graphs are included which present both local and average heat transfer coefficients and liquid film thickness for Reynolds numbers from 100 to 50,000 and Prandtl numbers from 0.1 to 10.0 for a wide range of vapor loadings. **Thermal Conductivity of Some Mesomorphic Compounds,** J. B. McCoy and L. S. Kowalczyk. The thermal conductivity of three mesomorphic compounds (*p*-hexyloxybenzoic acid, *p*-heptyloxybenzoic acid, and *p,p'*-azoxyanisole) was measured by a highly refined modification of the hot-wire method at temperatures ranging from 90° to 160°C. The thermal conductivity of the investigated compounds decreased with temperature but showed a sudden and distinct increase at the temperature at which the compounds were passing from the cloudy to the clear melt phase. **Approximate Theory for Film Boiling on Vertical Surfaces,** Y. Y. Hsu and J. W. Westwater. A new equation is presented for film boiling at a vertical surface for saturated liquids in the absence of forced flow. The principal approximations are that vapor flow near the low end of the heating surface is viscous and Bromley's equation is valid there, turbulence develops where the local Reynolds number reaches about 100, and in the turbulent region of the heating surface thermal resistance is due entirely to the laminar sublayer. Tests with five liquids on tubes having lengths between 2 and 6.3 in., and a range of ΔT from 200° to 780°F., show that the equation is reliable to within an average error of about ± 32%. **Heat Transfer in Saturated Boiling,** Yan-Po Chang and N. W. Snyder. This paper considers the heat transfer by boiling liquid from a horizontal surface. The presence of vapor bubbles contributes three effects to the heat transfer: destruction of the wave motion adherent to natural convection; increase of the effective thermal conductivity due to the eddy motion, or agitation effect; and change of specific heat capacity due to change of phase, or latent heat effect. The agitation effect is assumed to extend to the whole regime of nucleate boiling, whereas the latent heat effect starts to become significant only when the condition corresponding to the peak heat flux is approached. Six-dimensional parameters are found from the equations of momentum and energy. An equivalent thermal diffusivity of boiling liquid is defined and correlated from these six parameters. A general equation of heat transfer coefficient is obtained in both convection and nucleate boiling. Peak heat flux and its corresponding temperature difference are determined according to the mechanism of agitation and latent heat transport. Calculated results agree well with test data of previous investigators for dependence on both temperature and pressure. **Population of Active Sites in Nucleate Boiling Heat Transfer,** R. F. Gaertner and J. W. Westwater. Counts of active bubble-producing sites were determined throughout most of the nucleate region for a boiling liquid. An aqueous solution of nickel salts containing 20% solids was boiled at atmospheric pressure on a horizontal, flat, copper surface 2 in. in diameter in a 7½-in. vessel with no forced convection. The technique for determining active sites consisted of plating a thin layer of nickel on the copper surface during the boiling runs and subsequently counting the number of pin holes in the plate. The heat flux was varied from 7,680 to 535,000 B.t.u./(hr.)(sq. ft.) and the Δt from 17.3° to 218.8°F. Counts of active sites were obtained from zero to a maximum of 1,130/sq. in. at 317,000 B.t.u./(hr.)(sq. ft.). A random geometrical distribution of active sites was revealed by a photographic study of the nickel-plated heated surface. For this system a linear relationship between the number of active sites and the heat flux, as suggested by Jakob, is nonexistent. The heat flux was proportional approximately to the square root of the number of sites. Widely known theoretical analyses for nucleate-boiling heat transfer do not include the functionality in the latter manner. **The Role of Surface Conditions in Nucleate Boiling,** Peter Griffith and John D. Wallis. A study of nucleation from a single cavity indicates that cavity geometry is important in two ways. The mouth diameter determines the superheat needed to initiate boiling, and its shape determines its stability once boiling has begun. Contact angle is shown to be important in bubble nucleation primarily through its effect on cavity stability. Contact-angle measurements made on clean and paraffin-coated stainless steel surfaces with water show that the contact angle varies between 20 and 110 deg. for temperatures from 20° to 170°C. On the basis of single-cavity nucleation theory, it is proposed to characterize the gross nucleation properties of a given surface for all fluids under all conditions with a single group having the dimensions of length. Finally this characterization is shown experimentally to be adequate by boiling water, methanol, and ethanol on different copper surfaces finished with 3/0 emery and showing that the number of active centers per unit area is a function of this variable alone. **Heat Transfer from Premixed Gas Flames in a Cooled Tube,** Donald W. Sundstrom and Stuart W. Churchill. Premixed propane and air were burned inside a water-cooled 1-in. I.D. stainless steel tube to determine the effect of process variables on the local rate of heat transfer to the wall. The flame was stabilized within the tube by central bluff-body flame holders. The frequency and amplitude of the longitudinal (organ pipe) oscillations generated by the combustion process were also measured, acoustical dampeners being used to modify the oscillations. Screeching combustion (strong transverse oscillations(could not be established in the 1-in. tube. The local heat transfer rate was observed to go through a maximum downstream from the flame holder for all conditions. The flame-generated oscillations and the process variables affected the magnitude and location of this maximum, but the heat transfer rates downstream from the maximum were in reasonable agreement with those predicted for an ordinary stream of hot gas. **The Effect of Electrolytic Gas Evolution on Heat Transfer,** F. O. Mixon, Jr., Wan Yong Chon, and K. O. Beatty, Jr. As part of a long-range study of the mechanism of heat transfer in boiling, the effect of electrolytic bubble generation on the heat transfer coefficients between a horizontal copper surface and a pool of stagnant water was measured. The metal surface was pure copper about 2 in. by 2 in. and faced upward 10 in. below the liquid surface. Temperature of the block was varied by the use of electrical resistance heaters. Electrolysis was carried out by application of a direct current between the copper heating surface and a large anode located some distance from this surface. Small amounts of sodium hydroxide were added to the water to facilitate the electrolysis. The temperature of the heating surface was varied from room temperature up to 310°F., and the bath temperature was held approximately constant at 80° to 100°F. Electrolysis current was varied from 0 to 545 amp./sq. ft. Material enhancement of heat transfer coefficients was noted with the electrolytically generated bubbles, when the surface temperature was both below and above the boiling point of water in the bath. Interpretation of the data is made with special reference to its contribution to heat transfer in the cooling of nuclear reactors where liquids may be subjected to surface temperatures in excess of their boiling points. **Two-Phase Flow Rates and Pressure Drops in Parallel Tubes,** H. L. Foltz and R. G. Murray. Two-phase Freon-114 flow rates and pressure drops were measured in an electrically heated natural-circulation loop containing two 4- and two 8-ft. lengths of vertical brass pipes. The flow rates through the 8-ft. pipes increased with an increase in heat flux, reached a maximum at 3,200 B.t.u./(hr.) (sq. ft.) and then decreased as the heat flux was increased. The maximum obtainable heat flux, for both long and short pipes, was limited to 14,000 B.t.u./(hr.) (sq. ft.) because of the limitations on the electrical heaters. The flow rates through the 4-ft. pipes continued to increase with increases in heat flux up to the maximum. An equation which assumed fog flow, or no slip, was developed from a mechanical energy balance to calculate two-phase pressure drops. This equation, containing only the independent variables of heat input, flow rate, and pipe length, was programed for an analogue computer, and a series of pressure-drop curves, representing different flow rates, as a function of heat input was drawn from each pipe length. The calculated pressure drops were approximately 25% lower than the measured values, owing primarily to the effect of slip and subcooling at the inlet end of each tube. **A Theory of Local-Boiling Burnout and its Application to Existing Data,** Louis Bernath. A theory of local-boiling burnout is presented based on an analogy between the microconvective processes in local boiling and the conventional approach to turbulent diffusion processes. This theory describes, in a plausible manner, the physical significance of the mathematical relationships evolved in an empirical method of prediction of the burnout heat flux for water with local boiling over a wide range of experimental conditions. The prediction method is generalized to liquids other than water. Available data are assembled and discussed, and the results of the prediction method are compared with experimental values. **Radiant Heat Transfer Through the Atmosphere,** Jin H. Chin and S. W. Churchill. The transmission of thermal radiation from plane-parallel and point sources above and spherical sources within the atmosphere is investigated theoretically. The atmosphere is idealized as a uniform plane-parallel dispersion of finite height situated above a diffusely reflecting surface. Expressions for the scattering and absorbing properties of the atmosphere are developed from the fundamental optical properties of the gas molecules and suspended materials. Analytical solutions for the transmission are derived by utilizing a two-component representation for the intensity with a second pair of components for the radiation reflected by the surface.

These expressions and solutions have a variety of engineering applications. Illustrative calculations are presented for representative conditions. **Condensation on a Horizontal Rotating Disk,** S. S. Nandepurkar and K. O. Beatty, Jr. A rotating, horizontal, water-cooled disk 5 in. in diameter was used as the condensing surface for pure vapors of methanol, ethanol, and Freon-113 all at atmospheric pressure. Rotational speeds of the condenser were varied over the range of 400 to 2,400 rev./min. Heat transfer coefficients were calculated by use of measurements of surface temperature from thermocouples located at three positions on the rotating surface. Theoretical analysis of the problem of condensation on such a rotating surface resulted in the prediction of uniform coefficient over the entire surface (that is a uniform condensate-layer thickness) and an increase in heat transfer coefficient proportional to the square root of the rotational speed. Experimental results from the three surface thermocouple locations confirmed that the coefficients were substantially constant over the surface. Measured coefficients were about 20% less than those predicted theoretically and showed slight increase in deviation as the rotational velocity increased. A design equation is recommended covering data for all three fluids over the range of rotational speeds investigated. Observed heat transfer coefficients for methanol ranged from 600 B.t.u./(hr.) (sq. ft.) (°F.) at 400 rev./min. to 1,300 at 2,400 rev./min. Fore thanol, values ranged from 470 at 400 rev./min. to 1,100 at 2,400 rev./min. For Freon-113, the range was from 340 at 400 rev./ min. to 610 at 2,400 rev./min. The discrepancy between measured heat transfer coefficients and predicted values is believed to be due to neglect of the effect of vapor drag on the condensate in making the theoretical analysis. **Condensation of a Vapor in the Presence of a Noncondensing Gas,** W. W. Akers, S. H. Davis, Jr. and J. E. Crawford. Experimental measurements of the rate of condensation of ethanol in the presence of nitrogen, helium, and carbon dioxide, and of carbon tetrachloride in the presence of nitrogen and carbon dioxide, were made on a vertical plate. The results were satisfactorily correlated in terms of the Schmidt number and a generalized Grashof number. The results on a horizontal tube for other systems are in substantial agreement with this correlation. **Condensation Inside a Horizontal Tube,** W. W. Akers and H. F. Rosson. Heat transfer data were taken for methanol and Freon-12 condensing inside a horizontal tube over considerable ranges of pressure, temperature driving force, liquid loading, and vapor velocity. For condensation in a horizontal tube three primary regions of flow are postulated: semistratified flow (annular condensation and run down superimposed on stratified flow), laminar annular flow, and turbulent annular flow. A semitheoretical equation is developed and shown to be applicable to both semistratified and laminar annular flow. Other equations must be used for turbulent annular flow. **Local Heat Transfer and Pressure Drop for Refrigerant-22 Condensing in Horizontal Tubes,** Manfred Altman, F. W. Staub, and R. H. Norris. Local heat transfer coefficients and pressure drop were determined for refrigerant-22 condensing in an 8-ft. long, 0.343-in. I.D. horizontal tube. The method of Carpenter and Colburn was used to correlate the data, and an empirical correction factor was derived that enabled the data in the desuperheating region also to be correlated by this simplified method. The analyses of Seban and Rohsenow were modified to include the effect of high vapor shear in horizontal tubes. This theoretical approach is well supported by the experimental data when the method of Martinelli-Nelson is employed to compute the shear stress at the tube wall. **Heat and Mass Transfer Analogy: An Appraisal Using Plant Scale Data,** J. F. Revilock, H. Z. Hurlburt, D. R. Brake, E. G. Lang, and D. Q. Kern. Chilton and Colburn presented the analogy which relates combined heat and mass transfer. Simultaneously Colburn and Hougen published a condenser-cooler design method employing the analogy. It has been regarded as the most powerful tool for computing the rate of condensation of a vapor from a noncondensable gas, and numerous papers have appeared since which endeavor to refine or shorten the time requirement for condenser-cooler design. In the twenty-five years since the appearance of both papers their precision has never been confirmed in the literature in a large-scale application. The performance of a battery containing up to six parallel clean 37-in. I.D. counterflow condensers with 14-ft. long tubes is reported and analyzed. The validity of Kern's exception to Colburn and Hougen's design method is also reviewed on the basis of the data. **Temperature Distribution in Solids with Electrical Heat-Generation and Temperature-Dependent Properties,** R. P. Stein and M. U. Gutstein. Computations of temperature distributions in solids of simple shape with internal heat generation produced by the passage of an electrical current through the solid become somewhat complicated when the temperature dependence of electrical conductivity must be taken into account. This paper presents analytical solutions for a special case of temperature dependence which form the bases for developing simple criteria for determining when temperature dependence needs to be taken into account. It is shown that for nearly all metals temperature changes in the order of hundreds of degrees are required before significant effects of electrical-conductivity temperature dependence are realized. Also presented are convenient numerical procedures especially suitable for hand computation of temperature distributions when both electrical and thermal conductivity temperature dependences must be considered. The flat slab, cylindrical rod, and hollow cylinder are the shapes considered. **Determination of Core Dimensions of Cross-Flow Gas-to-Gas Heat Exchangers,** P. S. Lykoudis and M. R. Shastri. A procedure for rapid calculation of the core dimensions of a gas-to-gas cross-flow heat exchanger is presented which prescribes the inlet condition of each fluid, the pressure drops, the temperature change of one of the fluids, and the core geometry. The five basic equations containing five unknowns are reduced to a single equation with one unknown which can easily be solved. Numerical examples show the application of the method. **Analytical Study of Heat Transfer Rates for Parallel Flow of Liquid Metals Through Tube Bundles: Part I,** O. E. Dwyer and P. S. Tu. Nusselt numbers have been calculated for fully developed, turbulent, and parallel flow of liquid metals through staggered tube bundles by a method analogous to that of Lyon for flow of liquid metals inside circular tubes. The tubes were assumed to be arranged on an equilateral triangular pitch. A constant heat flux from the outer surfaces of the tubes was assumed, and the model of an annulus was used; that is the heat leaving each tube was assumed to be picked up by the flowing metal in an imaginary annulus surrounding the tube, the outer circumference of the annulus circumscribing an area equal to the total cross-sectional hexagonal area associated with each tube. The results are based on the velocity distribution data of Rothfus, Walker, and Whan for flow in concentric annuli. The effects on the Nusselt number of Prandtl number, Peclet number, tube diameter, pitch-to-diameter ratio, and the ratio of eddy diffusivity for heat transfer to that for momentum transfer have been determined. **Assessment of Heat Exchanger Data,** Sverre K. Jenssen. To obtain the most economical solution of a heat exchange problem, it is important to choose an effective design of heat transfer surface and optimum operating conditions for the heat exchange process. A comparison symbol J is introduced for facilitating the assessment of heat exchanger performance and/or operating requirements.

Every heat exchange problem where pressure drop and temperatures are given has a fixed *J* which indicates how much pressure drop is used for each heat transfer unit. As *J* also gives the ratio between power requirements and heat transfer capability, it permits a simple estimate of total yearly costs for carrying out heat exchange. Curves based on such cost estimations show that the same value of *J* can be used for a wide variety of heat exchanger applications with, in each case, a close approach to the economic optimum. Other curves giving the annual profit from heat recovery show that optimum can be approached for a number of heat recovery applications at the same temperature difference. **True Temperature Difference in a 1-2 Divided-Flow Heat Exchanger,** D. L. Schindler and H. T. Bates. The 1-2 divided-flow heat exchanger has been mathematically described in terms of traditional dimensionless quantities. A Ten Broeck chart was constructed having correction-factor parameters for easy comparison with counterflow. In cases where the exit temperatures approach or cross each other, 1-2 exchangers require an excessive surface area, and some other arrangement must be used to increase the effectiveness of heat transfer. The divided-flow exchanger utilized the available temperature difference efficiently and hence represents a marked improvement over the conventional 1-2 exchanger. At the same time the pressure drop in the 1-2 divided-flow exchanger is approximately the same as that in a conventional 1-2 exchanger of equal surface.

ERRATUM

We regret that "Pressure Drop and Power Requirements in a Stirred Fluidized Bed" by Max Leva, which appeared on page 688 of the December, 1960, issue of the *A.I.Ch.E. Journal,* was omitted from the index. We would appreciate it if all subscribers would insert it in its proper place in the index for 1960 for future reference.

Computer Program Abstracts

Readers of the *A.I.Ch.E. Journal* who are interested in programming for machine computation of chemical engineering problems will find in each issue of *Chemical Engineering Progress* abstracts of programs submitted by companies in the chemical process industries. Collected by the Machine Computation Committee of the A.I.Ch.E., these programs will be published as manuals where sufficient interest is indicated. The following abstracts have appeared this year:

CEP (October, 1960), p. 86

- Platinum Resistance Thermometer Conversion Table (038)
- A Design Method for Economical Drying of Moisture from Solids (057)
- Molecular Weight by Light Scattering (062)

CEP (November, 1960), p. 70

- Least Squares Fit to Relaxation Equation (050)
- Design of Optimum Multifactorial Experiments (064)

CEP (January, 1961), p. 90

- Comparison of Means (Scheffe' Test) (063)
- NY BWR1 and NY TEQ1 (065)

CEP (February, 1961), p. 80

- Analysis of Variance (067)
- Thermal Rating of Shell and Tube Heat Exchangers—Condenser or Heater—Vapor in Tubes (069)