$$Y = a\,V + b \qquad (1)$$

A relationship between slope a and length l was found empirically, which, introduced into Eq. 1, gives:

$$Y\,(\%) = 29.5 - 1.48\,Q\,l^{0.37} \qquad (2)$$

l : length of zone A (cm)

Q : Cl_2 flow rate (cm^3/s)

The chlorine conversion rate is then given by Eq. 3

$$\%\ \text{conversion} = (29.5 - 1.48\,Q\,l^{0.37})\,(1 - e^{-3.15l}) \qquad (3)$$

Equation 3 allows the conversion rate and hence the production of our reactor to be predicted.

Curves were plotted using data obtained from Eq. 3. For example, in the case of Figure 3, reaction rate was computed for different length and flow rates, the amount of absorbed photons being constant. It is interesting to note that in this case, for each value taken for l, there is a particular flow rate for which reaction rate is optimized. The results presented in Figure 3 are consistent with the theory proposed by Lucas (1982).

These experiments demonstrated once more the possibility of transfer of radicals through a grid, and the potential advantages of segregated photoreactors.

The effect of the length of the irradiation chamber is underlined, and the data obtained are in good agreement with the work of Lucas (1973, 1982), which deals with the transfer of any kind of activated particle. It would, therefore, be interesting to investigate the transfer of activated species other than radicals.

LITERATURE CITED

Cassano, A. E., and J. M. Smith, "Photochlorination in a Tubular Reactor," *AIChE J.*, **12**, 1124 (1966).

Chiltz, G., et al., "Atomic Chlorination of Simple Hydrocarbon Derivatives in the Gas Phase," *Chem. Rev.*, **40**, 355 (1963).

Dworkin, D., "Free Radical Generation and Transfer in the Vapor Phase Chlorination of Chloroform," MS. Thesis, Northwestern Univ., Evanston, IL (1977).

Dworkin, D., and J. S. Dranoff, "Free Radical Transport in a Photochemical Reactor," *AIChE J.*, **24**, 1134 (1978).

Huff, J. E., and C. A. Walker, "The Photochlorination of Chloroform in Continuous Flow Systems," *AIChE J.*, **8**, 193 (1962).

Lucas, G., "A New Concept in Oximation by Nitrosyl Chloride Molecule," *Info. Chimie*, **99**, 77 (1971).

———, "Reactions par Transfert de Radicaux Libres," *ivid.*, **126**, 87 (1973).

———, "Transfer Theory for Trapped Electromagnetic Energy," *Technique et Documentation*, Lavoisier, Paris (1982).

Mazich, K. A., "Free Radical Transport and Light Transmission in the Two-chambered Photochemical Reactor," MS. Thesis, Northwestern Univ., Evanston, IL (1980).

Noyes, R. M., "Photochemical Space Intermittency. A Proposal for Measuring Diffusion Coefficients of Reactive Free Radicals," *J. Am. Chem. Soc.*, **81**, 566 (1959).

Richard, M., "Nouveaux Types de Réacteur Photochimique Industriel," Thèse de Docteur-Ingénieur, I.N.P.T., Toulouse, France (1982).

Ziolkowski, D., A. E. Cassano, and J. M. Smith, "Effect of Wall Deposit on Photochlorination Kinetics," *AiChE J.*, **13**, 1025 (1967).

Manuscript received November 1, 1982; revision received February 16, and accepted March 4, 1983.

Analytic Representation of Convective Boiling Functions

SERGIO EDELSTEIN,
A. J. PEREZ,
and J. C. CHEN

Department of Chemical Engineering
Lehigh University
Bethlehem, PA 18015

A widely used correlation (Collier, 1972; Hsu and Graham, 1976; Rohsenow, 1973) for prediction of convective boiling heat transfer coefficients was developed by Chen (1966). Although alternative approaches have been proposed by others (Borge et al., 1982), the Chen correlation remains widely used (Butterworth, 1982). Based on the concept that heat transfer is caused by two interacting, additive mechanisms (the ordinary macroconvective mechanism and a bubble-induced microconvective mechanism), the Chen correlation was first derived for the case of saturated boiling of single-component nonmetallic fluids and later extended to liquid metals (Chen, 1963) and subcooled boiling (Butterworth, 1972).

The Chen correlation includes two dimensionless empirical functions: an effective two-phase Reynolds number function, F, and a bubble-growth suppression function, S. In the original correlation, F and S were present as empirical graphical functions. Presently, most users utilize tables or piecewise fits to these graphical functions. Explicit expressions for these functions would be more useful for computer design and performance studies, especially when analyzing the parametric sensitivity of heat transfer rate to the various operating variables. As a minor, but useful contribution, this paper presents analytical representations for the F and S functions. Momentum transfer analogy is used to develop a physically meaningful explicit representation for the two-phase Reynolds number function, F. Additionally, an explicit equation is also developed (empirically) for the supression function, S.

As shown by Chen (1966), the F function can be related to the Lockhart-Martinelli pressure drop factor by means of the heat momentum transfer analogy,

$$f = (\phi_{Ltt})^{0.89} \qquad (1)$$

where ϕ_{Ltt} is defined as the ratio of frictional pressure drop for two-phase flow to that for liquid-phase flow alone.

The Martinelli parameter (Lockhart and Martinelli, 1949) is defined as,

$$X_{tt}^2 \equiv \left(\frac{\phi_{vtt}}{\phi_{Ltt}}\right)^2 \qquad (2)$$

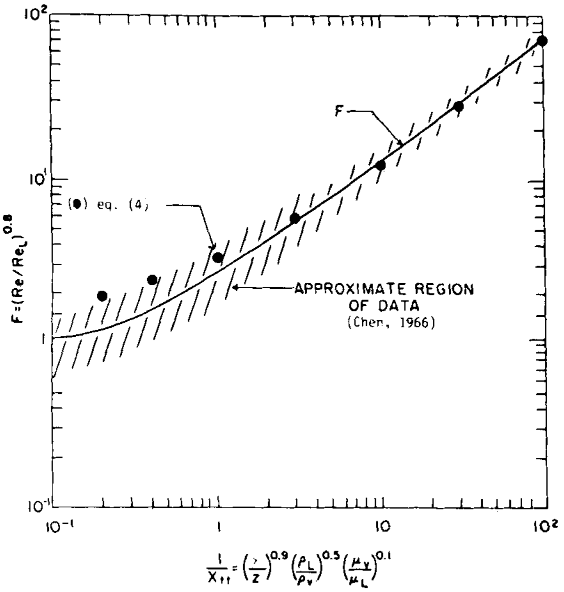

Figure 1. Comparison between the experimental data and equation (4).

Using Wallis' (1969) separate cylinders model for turbulent flow,

$$\left(\frac{1}{\phi_{Ltt}^2}\right)^{1/n}+\left(\frac{1}{\phi_{vtt}^2}\right)^{1/n}=1 \qquad (3)$$

when $n \cong 4$ for the turbulent-turbulent regime. Combining Eqs. 1 to 3, we obtain the final expression for the F function,

$$F=[1+X_{tt}{}^{-0.5}]^{1.78} \qquad (4)$$

where

$$X_{tt}{}^{-1}=\left(\frac{x}{1-x}\right)^{0.9}\left(\frac{\rho_L}{\rho_v}\right)^{0.5}\left(\frac{\mu_v}{\mu_L}\right)^{0.1}$$

Figure 1 shows that Eq. 4 provides a good representation of the original empirically derived F function.

The following empirical correlation is proposed to fit the suppression function S,

$$S=0.9622-0.5822\left[\tan^{-1}\left(\frac{Re}{6.18\times10^4}\right)\right]\text{(rad)} \qquad (5)$$

where

$$Re=Re_L\cdot F^{1.25}$$

As shown in Figure 2, Eq. 5 gives a very good representation of the experimental values of the S function, with a slight overprediction in the range of high Reynolds numbers. However, the microconvective contribution is very small in this range and the error introduced in the prediction of the overall two-phase heat transfer coefficients is negligible.

The derivatives of the two correlating functions F and S, obtained from Eqs. 4 and 5, are:

$$\frac{dF}{d(1/X_{tt})}=0.89\,X_{tt}{}^{0.5}[1+X_{tt}{}^{-0.5}]^{0.78} \qquad (6)$$

$$\frac{dS}{dRe_L}=F^{1.25}\frac{dS}{dRe}=-\frac{3.6\times10^4}{3.82\times10^9+Re^2}[1+X_{tt}{}^{-0.5}]^{2.23} \qquad (7)$$

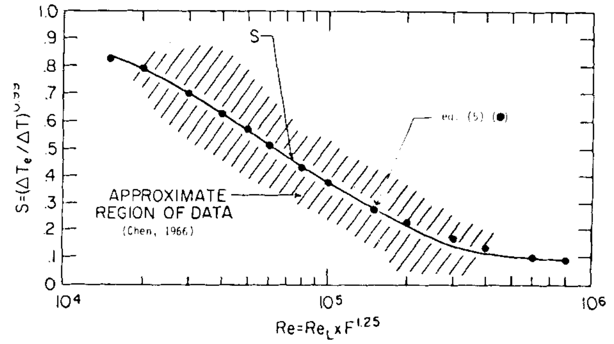

Figure 2. Comparison between the experimental values of the suppression function and equation (5).

The above analytic representations for the F and S functions should be helpful in the thermal design of convective boiling systems.

NOTATION

F = Reynolds number factor, $(Re/Re_L)^{0.8}$
Re = effective Reynolds number for two-phase fluid
Re_L = Reynolds number for liquid fraction
S = suppression factor
x = weight fraction, vapor
X_{tt} = Martinelli parameter
z = weight fraction, liquid

Greek Letters

ϕ_{Ltt} = two-phase pressure drop factor, liquid
ϕ_{vtt} = two-phase pressure drop factor, vapor
μ_L = viscosity, liquid
μ_v = viscosity, vapor
ρ_L = density, liquid
ρ_v = density, vapor

LITERATURE CITED

Bjorge et al., *Int. J. Heat and Mass Transfer*, **25**, 753 (1982).
Butterworth, D., "Flow Boiling," *Proc. of Int. Heat Transfer Conf.*, **1** (1982).
Butterworth, D., *Convective Boiling and Condensation*, Ed., J. G. Collier, 2nd Ed., McGraw-Hill, 219 (1972).
Chen, J. C., Ann. Conf. on High Temp. Liquid Metal Heat Transfer Technol., ORNL (Sept., 1963).
Chen, J. C., *I&EC Process Des. and Devel.*, **5**, No. 3, 322 (1966).
Collier, J. G., *Convective Boiling and Condensation*, McGraw-Hill Book Co., 211 (1972).
Hsu, Y. Y., and R. Graham, *Transport Processes in Boiling and Two-phase Systems*, McGraw-Hill Book Co., 239 (1976).
Lockhart, R. W., and R. C. Martinelli, "Proposed Correlation of Data for Isothermal Two-Phase Two-Compoent Flow in Pipes," *Chem. Eng. Prog.*, **45**, 39 (1949).
Rohsenow, W. M., and J. P. Hartnett, Eds., *Handbook of Heat Transfer*, 13.39 (1973).
Wallis, G. B., *One-Dimensional Two-Phase Flow*, McGraw-Hill Book Co., 49 (1969).

Manuscript received July 30, 1982 and accepted March 4, 1983.