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A Correlation for the Pool Boiling Enhancement Factor from Low Finned Tubes

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I. Introduction

The surface structure has been proved either experimentally or theoretically to have a vital role on the heating element performance during the boiling process, Kurihara and Myers (1960) and Griffith and Wallis (1960). Ahmad (2012) investigated saturated pool boiling of R-123 from five horizontal copper surfaces modified by different treatments. He has found that significant enhancement of heat transfer was demonstrated with increasing surface roughness. Fig. 1shows a schematic diagram of one of the available commercial surfaces implemented in boiling process known as a low finned tube.

Marto and Lepere (1981) showed that the pool boiling heat transfer coefficient when boiling R-113 and FC-72 was strongly related to the liquid-surface combination factor, the past history of the surface and the operating liquid properties. Yilmaz et al. (1981) found that the enhancement in the boiling heat transfer coefficients of p-xylene and isopropyl alcohol depends on the operating conditions and boiling liquid type. Marto and Hernandez (1983) reported an enhancement factor of about three times when boiling R-113 on the Gewa-T surface at atmospheric pressure. Hahne and Muller (1983) have found an improvement in the boiling heat transfer coefficient of R-11 when compared the finned tubes with that of the smooth one.

Kandikar and Howell (1996) reported an increase in bubble activity on a micro fin surface when compared to a plain surface for flow boiling investigation. Yuming et al. (2003) made a comparison between the smooth and enhanced tubes for bubble nucleation characteristics. These are assigned as growth rate, departure diameter, frequency, active site density and rise velocity. The effects of physical properties on the bubble dynamics were clear especially the departure diameter and the nucleation site density.

Yilmaz and Westwater(1981) concluded that the enhancement in heat transfer performance depends on the enhanced surface structure and liquid properties. In addition to these factors, Tarrad (1991) has concluded that the enhancement factor of the enhanced tubes is also a strong function of whether the boiling fluid was a pure or mixture substance. Ricardo (1984) has concluded that the enhancement shows a dependency on the vapor density, latent heat and thermal conductivity of the boiling fluid.

The operating heat flux, pressure, surface condition and thermal physical properties will be incorporated in a simple correlation to predict the enhancement factor. Eleven pure fluids boiling on a low finned tube, possessing quite a good range of thermal properties and operating pressure will be implemented to establish the present correlation.

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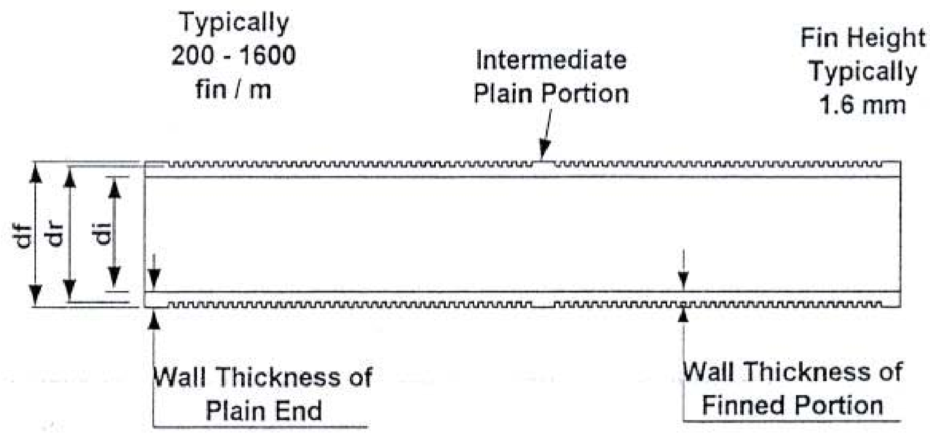

Figure 1 : A schematic diagram for a typical low finned tube

II. Available Correlations

The available correlations in the open literature are either semi-empirical or they require a large number of parameters to be determined prior to the application of such correlations, Tarrad (2011). This of course will exhibit an additional difficulty of handling the enhanced surface effect on the boiling heat transfer performance prediction.

Palen and Yang (1983) proposed a correlation for the prediction of the boiling heat transfer coefficient on low finned tube in the form:

$$\alpha_{L-F} = F_c F_e \eta \alpha_{pla.} + \alpha_{nc} \qquad (1)$$

Where ($\alpha_{pla.}$) is the boiling heat transfer coefficient achieved by a plain tube and (α_{nc}) is the natural convection part of the heating surface which is usually small; of the order of (250) W/m^2 K for hydrocarbons. The mixture correction factor (F_c), and the fin efficiency (F_e) were given a specified numerical values. They represented a formula for the surface factor (η) in the form:

$$\eta = C_1 \left(\frac{q}{q_{ref}} \right)^{m_1} \left(\frac{p}{p_c} \right)^{m_2} F_c^{\,m_3} \qquad (2)$$

The authors postulated that this expression has been found by the (HTRI) organization and no numerical values for the exponents and the empirical constant were specified.

Xin and Chao (1987) presented a model to describe the boiling heat transfer coefficient of flat *Gewa-T* surfaces. The resultant correlation has the form:

$$Nu = 3.76 \left(\frac{2\,H+L}{2\,D} \right) {Ar_D}^{1/3}\, {Re_l}^{-0.15} We^{0.29} {Pr_l}^{0.76} \qquad (3)$$

Where:

$$Nu = \frac{q\,s}{\Delta T_s k_l} = \frac{h\,s}{k_l} \qquad (4.a)$$

$$Ar_D = \frac{g\,D^3}{{V_l}^2} \frac{\rho_l - \rho_g}{\rho_l} \qquad (4.b)$$

$$Re_l = \frac{2\,q\,s}{h_{fg}\,\mu_l} \qquad (4.c)$$

$$We = \frac{{q_{ev}}^2 s^2}{\sigma\,\rho_g {h_{fg}}^2\,D} \qquad (4.d)$$

$$Pr_l = \frac{V_l}{a_l} \qquad (4.e)$$

The authors tested the general formula, eq. (3), with many types of the Gewa-T surface boiling water, ethanol and R-113. The fin shape and structure has a variable fin gaps, pitches, and heights. They concluded that the expression presented in eq. (3) correlated the experimental data within accuracy of ($\pm$30%). Thome (1990) tested this correlation with data of different refrigerants (R-11, R-12, R-22, and R-113), isopropanol and p-xylene boiling on Gewa-T tubes. He concluded that this formula showed a poor agreement with the experimental data for the tested refrigerants.

Chen et al. (1989) proposed a model to predict the boiling heat transfer coefficients ofR-11from copper single and twin finned tube arrangements for the heat flux range (20) to (50) kW/m^2. Their correlation involved three empirical constants to be determined for each surface. Tarrad (1991) correlated his own results for boiling on the plain and enhanced surfaces at the atmospheric pressure as:

$$q = C_1 \Delta T^{\,n} \text{ for } 5 \le q \le 60 \text{ kW/m}^2 \qquad (5)$$

Where the empirical constant *(C_1)* and the wall superheat index *(n)* were given for each liquid - surface combination. These values showed a great dependence on the liquid properties and surface structure considered.

Tarrad (2007) attempted to formulate the enhancement factor for externally integral machined finned tubes boiling different liquids for a heat flux range between (10) kW/m^2 and (50) kW/m^2. The liquids considered were R-113, n-pentane, ethanol, water, p-xylene and R-11. The general form of his correlation can be expressed as follows:

$$\eta = C_{S,F}\left(\frac{\rho_l h_{fg}^{3/2}}{q}\right)^{0.1856}\left(\frac{cp_l\sigma}{k_l h_{fg}^{0.5}}\right)^{0.3}\left(\frac{p}{p_c}\right)^{-0.2} \quad (6)$$

The coefficient *($C_{S,F}$)* was given a different numerical value for each of the surface-liquid combination considered in the formulated correlation as tabulated values. This correlation showed a total absolute mean errors for the boiling heat transfer coefficient of (8%) and (9%) for the *low finned* and *Gewa-T* tubes respectively. For the same heat flux range and *R-113, n-pentane, ethanol, water* and R-11 boiling fluids, Tarrad (2011) has postulated a more comprehensive formula for the prediction of the pool boiling enhancement factor of *low finned* and *Gewa-T* tubes. His correlation had the form:

$$\eta = C_{S,F}\left(\frac{\rho_l h_{fg}^{3/2}}{q}\right)^{0.1806}\left(\frac{cp_l\sigma}{k_l h_{fg}^{0.5}}\right)^{1.7} \quad (7)$$

The coefficient *($C_{S,F}$)* was given a different numerical value for each of the considered surfaces as (0.389) and (0.48) for the *low finned* and *Gewa-T* tubes respectively. This correlation has showed a total mean absolute errors of the boiling heat transfer coefficients of (9.5%) and (13.5%) for the low finned and *Gewa-T* tubes respectively. A thoroughly inspection for this equation reveals that the predicted enhancement factor of *Gewa-T* surface is about 24% higher than that of the *Low finned* tube for the same test fluids and operating conditions.

III. The Present Correlation

a) Theoretical Background

The present correlation represents an extension to Tarrads' previous correlations, (2007) and (2011) as shown in equations (6) and (7) respectively, for the integrally machined enhanced tubes. It has been proved previously that the enhancement factor is directly proportional to the boiling liquid physical properties, operating pressure and heat flux, and enhancement structure, Marto and Lepere (1981), Yilmaz and West water (1981), Tarrad (1991) and many other investigators. The physical specification effect of the external enhancement of the boiling tube can be demonstrated by the surface area. It is suggested to formulate this parameter as a surface area ratio. This can be expressed as the ratio of the finned surface area to the fin root area of the tube, λ. As a matter of fact, this includes the effect of fin density defined as number of fins per inch; fin spacing, shape and height. The above argument can be expressed as:

$$\eta = \eta\left(h_{fg}, \rho_l, \rho_v, k_l, cp_l, \sigma, q, \lambda, p_r\right) \quad (8)$$

Where (η) refers to the enhancement factor defined by:

$$\eta = \frac{\alpha_{enh.}}{\alpha_{pla.}} = \frac{\Delta T_{pla.}}{\Delta T_{enh.}} \quad (9)$$

The enhanced surface nucleate boiling heat transfer coefficient is therefore has the form:

$$\alpha_{enh.} = \eta\alpha_{pla.} \quad (10.a)$$

In terms of the wall superheats in the form:

$$\Delta T_{enh.} = \frac{\Delta T_{pla.}}{\eta} \quad (10.b)$$

The plain nucleate pool boiling heat transfer coefficient, α_{pla}, is predicted by the available correlations such as Gorenflo (1993) equation in the following expression:

$$\alpha_{pla.} = \alpha_0 F_{PF}\left(\frac{q}{q_0}\right)^{nf}\left(\frac{R_p}{R_{p0}}\right)^{0.133} \quad (11.a)$$

The pressure correction factor (F_{PF}) is

$$F_{PF} = 1.2\,p_r^{\,0.27} + 2.5\,p_r + \frac{p_r}{1-p_r} \quad (11.b)$$

And

$$nf = 0.9 - 0.3\,p_r^{\,0.3} \quad (11.c)$$

Equations (11.b) and (11.c) are applied for all of the tested fluids in his correlation except water and Helium; for water the corresponding equations are:

$$F_{PF} = 1.73\,p_r^{\,0.27} + \left(6.1 + \frac{0.68}{1-p_r}\right)p_r^{\,2} \quad (11.d)$$

And

$$nf = 0.9 - 0.3\,p_r^{\,0.15} \quad (11.e)$$

In this method, R_{p0}=0.4 μm and q_0= 20000W/m^2. The value of the surface roughness R_p is set to (0.4) μm when unknown. The correlation is applicable for a reduced pressure range from about 0.0005 to 0.95. The reference heat transfer coefficient α_0 is listed in table (1) for the fluids considered in the present work.

Global Journal of Researches in Engineering (A) Volume XIV Issue V Version I Year 2014

For fluids which are not covered with the above correlation, it is suggested to use Mostinski (1963) correlationin the form:

$$\alpha_{pla.} = 0.1 p_c^{\ 0.69} q^{0.7} F(p_r) \tag{12.a}$$

Where

$$F(p_r) = 1.8 p_r^{\ 0.17} + 4 p_r^{\ 1.2} + 10 p_r^{\ 10} \tag{12.b}$$

In this formula, *(p_c)* is in bar, *(q)* in W/m^2 and (α_{pla}.) in W/m^2 K. This correlation has been tested for a long time with different liquids and showed acceptable agreement with the experimental data.

b) Correlation Formulation

In performing a dimensional analysis from the independent variables, the four dimensions will be considered for these variables (M, L, T, θ) together with four selected repeating variables (h_{fg}, ρ_l, k_l and cp_l). There are ten variables expressed in terms of four fundamental dimensions. Therefore, the equation relating the variables will contain six independent dimensionless groups including the reduced pressure group in the forms:

$$\pi_1 = \eta \tag{13.a}$$

$$\pi_2 = \frac{\rho_l h_{fg}^{\ 3/2}}{q} \tag{13.b}$$

$$\pi_3 = \left(\frac{\sigma}{k_l}\right) \frac{cp_l}{h_{fg}^{\ 0.5}} \tag{13.c}$$

$$\pi_4 = \frac{\rho_v}{\rho_l} \tag{13.d}$$

$$\pi_5 = \lambda \tag{13.e}$$

$$\pi_6 = \frac{p}{p_c} = p_r \tag{13.f}$$

Therefore, the suggested correlation has the following expression:

$$\pi_1 = \phi\,(\pi_2, \pi_3, \pi_4, \pi_5, \pi_6) \tag{14.a}$$

$$\eta = \phi\left\{\left(\frac{\rho_l h_{fg}^{\ 3/2}}{q}\right), \left(\frac{cp_l\,\sigma}{k_l h_{fg}^{\ 0.5}}\right), \left(\frac{\rho_v}{\rho_l}\right), (\lambda), (p_r)\right\} \tag{14.b}$$

This function may be represented in an equation with the form:

$$\eta = C_{S,F} \left(\frac{\rho_l h_{fg}^{\ 3/2}}{q}\right)^m \left(\frac{cp_l\,\sigma}{k_l h_{fg}^{\ 0.5}}\right)^n \left(\frac{\rho_v}{\rho_l}\right)^i \lambda^j \left(\frac{p}{p_c}\right)^\kappa \tag{14.c}$$

The independent groups (π_2) and (π_3) are reflecting the effect of the enhancement structure on the ability of bubble nucleation activity and departure parameters, the bubble size and frequency. The first group, (π_2), represents the rate of vaporization of the boiling liquid at the vicinity of the heating element. In fact it represents the intensity of bubble generation in the liquid layer penetrating through the tunnels of the surface structure. The second group, (π_3), corresponds to the effect of the surface tension force during the bubble detachment for the heating surface and the force implemented by the vapor generation and its movement in the structure tunnels at the heating surface.

The effect of the density difference between the vapor and liquid phases, which represents the effect of convective term during bubble nucleation and growth rate, is shown by (π_4). This will induce a momentum effect on the bubble nucleation and its intensity at the enhanced surface. The effect of the available finned tube surface area including the fin specifications on the heat transfer process is stated by the ratio (λ) as (π_5). The last group, (π_6), represents the effect of the operating pressure on the enhancement factor, hence the predicted nucleate boiling heat transfer coefficient.

The experimental data published in the open literature shown in table (2) is used in creation of the present correlation. More than (400) data points for the heat flux range between (10) and (50) kW/m^2 at different pressure were used. The thermal physical properties of the pure liquids tested by the present correlation are shown in table (3). These values are deduced from Tarrad (1991), Incropera and Dewitt (1990), Sinnott (1986) and Du Pont technical information catalogue.

Hence the best prediction of the enhancement factor for the whole range of the experimental data was obtained by:

$$\eta = 0.2411 \left(\frac{\rho_l h_{fg}^{\ 3/2}}{q}\right)^{0.0864} \left(\frac{cp_l\,\sigma}{k_l h_{fg}^{\ 0.5}}\right)^{1.40} \left(\frac{\rho_v}{\rho_l}\right)^{0.115} \lambda^{1.125} \left(\frac{p}{p_c}\right)^{-0.271} \tag{15}$$

The standard deviation of the fitted data was within (0.308) and the average absolute residual of the data points was (0.237) for this correlation. It showed a total mean absolute error of (13.3 %) for the whole ranges of heat flux and operating pressure implemented with the test fluids in the present work. Fig. 2. shows the residual versus the predicted values for the whole range of data points implemented by the present suggested correlation.

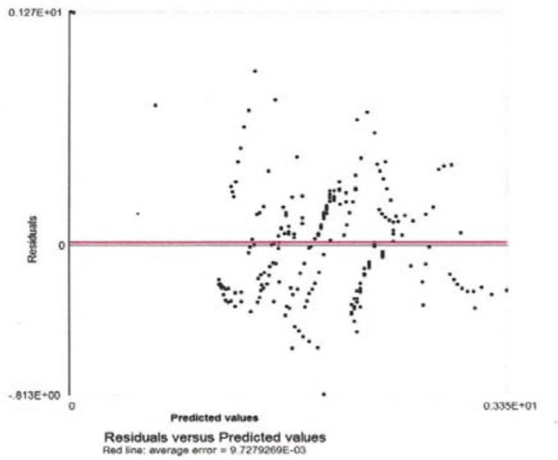

Figure 2 : A distribution diagram of the residual versus predicted values by the present correlation

The numerical values of *(m), (n), (i), (j)* and *(κ)* conclude that the enhancement factor shows a decrease as the operating heat flux, liquid surface tension, and the operating system pressure increase. This behavior is perfectly corresponds to the experimental data tested in the present work from the point of view of the effect of the heat flux and other physical properties on the predicted enhancement factor. The effect of (λ) is mainly revealed by increasing the exposed surface area of the tube to accomplish heat transfer and increasing the intensity of bubble nucleation.

With increase in the operating pressure, increase in reduced pressure, the enhancement in heat transfer achieved by the finned tube structure over the plain surface tends to decrease. This is exactly coinciding with the results obtained by different investigators such as Aniruddha and Yogendra (2006) and Yilmaz etal. (1981) when boiling fluids on enhanced surfaces. Palen and Yang (1983) concluded that the reduced pressure exponent, m_2, has a negative value in an enhancement correlation presented in the form of Eq.(2). However, no numerical values for all of the coefficients in the above equation were given in the open literature.

c) *Boiling Heat Transfer Coefficient Formula*

The final form of the suggested correlation of the present work is obtained by applying the above formula of the enhancement factor correlation, eq. (15), to the plain tube prediction equation either eq. (11) or eq.(12). The choice of implementation of the plain tube nucleate boiling heat transfer coefficient correlation depends on the accuracy and limitations of the considered equation. Gorenflo (1993) correlation has been used to predict the plain tube heat transfer coefficient for all of the test liquids in the present work. Thus, the general form of the present correlation is represented by eq. (16) as:

$$\alpha_{enh} = 0.2411\, \alpha_{pla}.\left(\frac{\rho_l h_{fg}{}^{3/2}}{q}\right)^{0.0864} \left(\frac{cp_l\,\sigma}{k_l h_{fg}{}^{0.5}}\right)^{1.40} \left(\frac{\rho_v}{\rho_l}\right)^{0.115} \lambda^{1.125} \left(\frac{p}{p_c}\right)^{-0.271} \quad (16)$$

IV. Results and Discussion

The present formula was tested against different liquids boiling on the plain and low finned surfaces at different pressures. The errors percentage of the predicted enhancement factor by eq.(15),is defined by the following expression:

$$(Err\%)_\eta = \frac{\eta_{pred.} - \eta_{meas.}}{\eta_{meas.}} \times 100 \quad (17)$$

The mean absolute error of the above expression is also calculated by:

$$(Err\%)_{abs.} = \Sigma\,|Err\%|\,/\,N \quad (18)$$

The correlation showed a quite high accuracy for the enhancement factor of the test surface. The total mean absolute error of the enhancement factor was within (13.3 %) for the whole range of data points. If the data points those located out of range were ignored, then the total mean absolute error will be improved to be (10.8 %) for more than (95 %) of the implemented data points. More than (95 %) of the experimental data fell within the zone bounded by the margin lines of (± 25 %). Fig. 3 shows the predicted and measured enhancement factors of the boiling liquids on the low finned tube structure. It is obvious that the predicted values of (η) by the form of eq.(15) showed a good agreement with those of the measured values and bounded within the limit of (±25%) for more than (95 %) of the data points considered in this work.

It is worthwhile to point out that the accuracy and limitation error margin of the present correlation of the nucleate boiling heat transfer coefficient is directly related to the plain tube prediction values. Therefore, it is recommended to select the most appropriate correlation for this object. We may conclude that the plain tube heat transfer coefficient correlations implemented in the present work are quite acceptable for the test fluids.

The present correlation for the prediction of the enhancement factor of the integral machined heating element showed a good response to the surface and liquid combination type. This concludes that the shape of enhancement and the boiling fluid combination has a great interaction effect on the behavior of the bubble nucleation in the machined tunnels where the flow of the boiling liquid is very high there. Further, the boiling liquid properties account for the higher part of the influence on the enhancement expected from a specified surface.

For example at atmospheric pressure, the enhancement factor produced by boiling n-pentane was ranged between (2) and (2.6) for the whole range of heat fluxes. The corresponding values of ethanol were bounded between (1.6) and (2). Whereas, boiling of water on this surface didn't show any augmentation for the boiling heat transfer coefficient. On the contrary, this surface showed deterioration for the performance of the heating element for most of the heat flux range. Further, it exhibited the same nucleate pool boiling heat transfer as that of the plain tube at a heat flux of (10) kW/m^2.

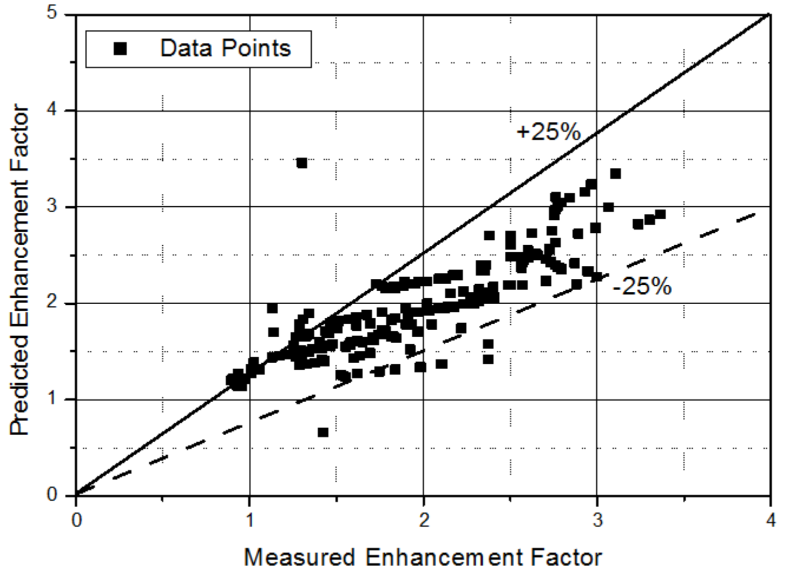

Figure 3 : A Comparison for the predicted enhancement factor with experimental data of the low finned surface

When boiling R-113; the enhancement factor was ranged between (1.8) and (2.6) for the entire range of the heat flux applied in the present work. This behavior of the variation was also exhibited by the present formula for the prediction of the enhancement factor of the enhanced surface.

V. Conclusions

A general form of correlation for the enhancement factor exhibited by the enhanced low finned surface was developed in the present investigation. The formula showed a good response to the variation of (η) when compared with the experimental data during boiling on the integral machined heating surface. The total mean absolute error of the correlation of the enhancement factor is within (13.3 %) for the data points used in the present work.

The suggested equation of the enhancement factor prediction exhibited an acceptable range of accuracy to be within (±25%) for the heat flux range (10 – 50) kW/m^2 and tested range of the operating pressure for more than (95 %) of the data point.

Although the present correlation has included some of the halocarbon refrigerants those to be at the phase out stage of application, but it will give an excellent indication for the substitutes to be used for existing refrigeration units. Further, it can be incorporated with models used for the design of the kettle reboilers and pool boiling evaporators used in a variety of industrial applications.

VI. Nomenclature

a: Thermal Diffusivity (m^2/s)

$C_{S,F}$: Liquid-Surface Contribution Factor in eq.(13.c), (Dimensionless)

C_1 : Empirical Constant in Equations

cp : Specific Heat of Fluid, (kJ/kg K)

d : Tube Diameter, (m)

h_{fg}: Heat of Vaporization, (kJ/kg)

k : Thermal Conductivity of Fluid, (W/m.K)

m : Constant in eq. (13.c), (Dimensionless)

n : Constant in eq.(13.c), (Dimensionless)

N : Number of Data Points, (Dimensionless)

p : Process Operating Pressure, (kPa)

q : Heat Flux Density, (kW/m2)

q_{ref}: Reference Heat Flux in eq.(2), (kW/m^2)

T : Temperature, (C^o)

ΔT: Wall Superheat, (deg C)

a) Greeks

α : Nucleate Boiling Heat transfer Coefficient, (kW/m^2 K)

η : Enhancement Factor of Boiling Heat Transfer Coefficient, (Dimensionless)
μ : Viscosity of Fluid, (Pa.s)
ν: *Kinematic Viscosity (m^2/s)*
ρ: Density of Fluid, (kg/m^3)
σ : Surface Tension, (N/m)

b) Subscripts

c : Critical Value
enh.: Enhanced surface Value
exp.: Experimental Value
l : Liquid
L-F: Low Finned Surface
o : Outside
pla.: Plain Tube Value
pred.: Predicted Value
r: Reduced or Measured at Fin Root

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Table 1 : Coefficients used with Gorenflos' correlation

Fluid	Chemical Formula	Molecular Weight (M) kg/kmol	α_0 (W/m^2 K)
R-11	CCl_3F	137.4	2800
R-12	CCl_2F_2	120.9	4000
R-22	$CHClF_2$	86.47	3900
R-113	$Cl_2FCCClF_2$	187.4	2650
R-114	$CClF_2CClF_2$	170.9	2800
R-123	CF_3CHCl_2	152.9	2600
R-124	$CHClFCF_3$	136.48	------
R-134a	CH_2FCF_3	102	4500
n-Pentane	C_5H_{12}	72.15	3400
Ethanol	C_2H_5OH	46.07	4400
Water	H_2O	18.02	5600

Table 2 : The structure characteristics of the surfaces tested in the present correlation

Surface Type	Source of Data	Tube d_o (in)	FPI	d_o/d_r (mm)	Fluid	Pressure (bar)
Plain	Hahne& Muller (1983)	3/4	-----	19/19	R-11	1.013
	Tarrad(1991)	3/4	-----	19/19	n-pentane, water, Ethanol, R-	1.013
	Webb (1994)	3/4	-----	19/19	113	1.013
	Palm (1995) *	3/4	-----	15.9/15.9	R-22	3 & 5
	Sugiyama (1991)	5/8	-----	15.9/15.9	R-22, R-134a	1.013
	Bertsch (1993)	5/8	-----	--------	R-114	1.77
	Gorenflo Correlation (1993)				R-124	-----
Low Finned	Hahne& Muller (1983)	3/4	19	18.9/15.9	R-11	1.013
	Tarrad(1991)	3/4	19	18.8/15.8	n-pentane, water, Ethanol, R-	1.013
	Webb (1994)	3/4	19	19/15.8	113	1.013
	Webb and Pais(1992)*	3/4	26	18.9/15.9	R-22	0.4-5.73
	Palm (1995)	3/4	26	18.9/15.9	R-11, R-12, R-22,R-123, R-	3 & 5
	Sugiyama (1991)	5/8	26	15.9/12.9	134a	1.013
	Bertsch (1993)	5/8	26 & 19	15.9/12.9	R-22, R-134a	1.77
	Kedzierski(1995)	5/8	19	15.9/12.9	R-114	0.391
					R-124	
					R-123	

* The pressure depends on the type of the boiling fluid

Table 3 : Selected physical properties of the correlated liquids at their normal boiling point

Liquid	*$T_{Boiling}$ (°C)*	*ρ_l (kg/m^3)*	*ρ_v (kg/m^3)*	*cp_l (kJ/kgK)*	*k_l (W/m K)*	*h_{fg} (kJ/kg)*	*$\mu_l \times 10^3$ (Pa. s)*	*σ (N/m)*	*P_c (bar)*
R-11	23.805	1479.4	5.853	0.8703	0.08898	180.33	0.405	0.018	44.1
R-12	-29.49	1486.67	6.343	0.8824	0.0882	165.69	0.360	0.0159	41.36
R-22	-40.8	1409.1	4.705	1.0916	0.1142	233.79	-----	0.01818	49.9
R-113	47.44	1507.42	7.419	0.98	0.07	147	0.5015	0.0159	34.15
R-114	3.763	1518.28	7.826	0.9621	0.0657	135.97	0. 3519	0.01332	32.6
R-123	27.85	1455.6	6.504	0.7191	0.076	170.4	0.408	0.0158 @ 25 C	36.68
R-124	-12.09	1473.76	6.652	1.0618	0.07963	165.93	0.4066	0.0142	36.243
R-134a	-26.1	1374.4	5.26	1.268	0.1055	214.94	0.406	0.01554	40.6
n-Pentane	36	610.598	2.9741	2.376	0.1096	356.3	0.1944	0.0143	33.7
Ethanol	78.3	736.45	1.50	3.0202	0.15147	823.83	0.4376	0.0177	63.8
Water	100	958.4	0.598	4.219	0.681	2257	0.2817	0.0589	221.2