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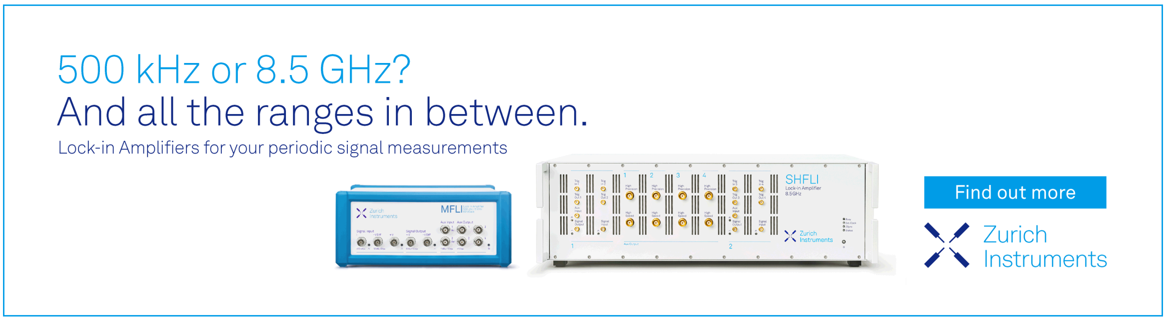

The Effect of Superposition Boiling Heat Transfer Coefficient in the Dryout Region

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Abstract. Miniaturization of the channel size of heat exchanging devices increases the surface to volume ratio, thus promotes higher heat transfer. Operating in two-phase flow further increases the coolant's ability to transfer heat due to the higher latent heat compared to sensible heat in a single phase flow. Many studies have been done to obtain heat transfer coefficient correlations that can accurately predict heat transfer phenomenon. But, there is a factor that influences their accuracy; the effects near the dryout region. Heat transfer has been found to decrease when dryout occurs. Available correlations cannot predict the occurrence of dryout in flow boiling heat transfer. This study analyzed the dryout region between three previous heat transfer coefficient correlations for propane (R290) of a similar form for different values of mass flux and heat flux as the vapour quality changed. It was found that disagreements between predicted and experimental coefficient occurred when the vapour quality is between 0.6 and 0.8. Multiobjective Genetic Algorithm (MOGA) optimization was then utilized to obtain simultaneous maximization of the nucleate boiling and forced convective boiling heat transfer, two mechanisms contributing towards boiling heat transfer and results showed that MOGA is capable of predicting the dryout region under optimized conditions. The optimization works showed that when the mass flux, G is around 200 kgm^{-2}s^{-2}, heat flux , q is around 19 kW m^{-2} , the vapour quality range must be taken into account which is between 0.0 until 0.8 before the dryout occurs. This can be used as guide to controlling heat exchanging devices such that two phase flow boiling occurs as predicted with the maximum heat transfer desired.

INTRODUCTION

In two phase flow boiling, specific patterns occur along the heated surface identified by different researchers; bubbly flow, slug flow, plug flow, wavy and annular flow in the horizontal tubes. Boiling mechanism has been widely accepted, as stated by Collier and Thome [3], to be governed by nucleate boiling and forced convection boiling. Yunos et al. [4] claimed that between these two mechanisms, nucleate boiling, h_{nb}, decreases while forced convective, h_{fo}, is increasing. Based on their study, they found that correlations by Liu and Winterton [5] , Bertsch et al. [6], and Mahmoud and Karayiannis [7] showed that heat transfer is approaching the dryout condition with decreasing of total two phase heat transfer coefficient value that can be seen around vapour quality of 0.6. This is of course undesirable since a heat exchanging device is designed and expected to perform in removing heat via two phase flow condition.

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Past experimental data from various authors successfully contribute in establishing the correlations for boiling heat transfer. Unfortunately, discrepancies were observed about the dryout region. Dryout region is an area that is closely associated with the annular flow regime prevalent in saturated flow boiling in small/mini-channels. Dryout occurred in increasing of vapour quality, x, but the ranges or area where the dryout region is cannot be predicted by the established correlations. Thus, this paper reports an analysis on the possible dryout region, on three past boiling heat transfer correlations for R290 (propane) developed to predict the two phase heat transfer coefficient. Environmentally friendly R290 [16] is currently being considered as an alternative refrigerant in today's cooling systems.

From perspectives of engineering, optimization can be done to find a combination of variables and controlling parameters for fulfilling the best working design. Optimization is known as a systematic process in identifying the set of variables in order to minimize or maximize the design objective which is better than trial and error processes. For this study, optimization is completed using genetic algorithm to obtain simultaneous maximization of nucleate boiling and forced convective heat transfer within a range of mass flux and heat flux as the vapor quality changes.

METHODOLOGY

Three correlations which are based on the superposition approach that have been developed from published data for small channels are studied. The correlations were claimed to be applicable for a range of refrigerants and experimental parameters and considered to be a generalized correlations.

For this study, the analysis is done by using the environmentally friendly working refrigerant R290, propane. R290 is a known natural refrigerant which is a non-toxic gas with zero ozone depletion potential (ODP) and very low global warming potential (GWP). The three correlations selected for this study are Choi et al. [8], Oh et al. [9], and Pamitran et al. [10].The three correlations are of the form:

$$h_{tp} = Sh_{nbc} + Fh_{fo} \tag{1}$$

where S is the nucleate boiling suppression factor, F is multiplier factor on the convective boiling contribution, h_{nbc} is nucleate boiling coefficient, and h_{fo} is forced convective boiling coefficient. For the nucleate boiling coefficient, h_{nbc}, it is taken from Cooper [11] which is:

$$h_{nbc} = 55Pred^{0.12}(-0.4343 lnPred)^{-0.55}M^{-0.5}q^{0.67} \tag{2}$$

where q is the heat flux (W m^{-2}), Pr is the reduced pressure ($Pred = \frac{\text{Psat}}{\text{Pcrit}}$) and M is the molecular weight (kg kmol^{-1}). By taking concern on the flow conditions (laminar or turbulent) in relation to the Reynolds number factor, F, Zhang et al. [12] introduced a relationship between F and the two-phase frictional multiplier that is based on the pressure gradient of only liquid flow, $\emptyset_f^2$. This relationship ($F = fn(\emptyset_f^2)$) is where $\emptyset_f^2$ is the form for four flow conditions according to Chisholm [13].For the liquid-vapor flow conditions of turbulent-turbulent (tt) , laminar-turbulent(vt) , turbulent-laminar (tv) and laminar-laminar (vv), the Chisholm parameter, C, are 20, 12,10, and 5, respectively. The C value in this study was obtained by considering the flow conditions of laminar and turbulent with thresholds of Re = 2300 and Re = 3000 for the laminar and the turbulent flows, respectively. Yang and Lin [14] equation for Reynolds number was referred for the laminar-turbulent transition. The F factor is developed as function of $\emptyset_f^2$:

$$\emptyset_f^2 = \frac{(-\frac{\partial p}{\partial z}F)_{tp}}{(-\frac{\partial p}{\partial z}F)_f} = 1 + C\left[\frac{(-\frac{\partial p}{\partial z}F)_g}{(-\frac{\partial p}{\partial z}F)_f}\right]^{1/2} + \frac{(-\frac{\partial p}{\partial z}F)_g}{(-\frac{\partial p}{\partial z}F)_f} = 1 + \frac{C}{X} + \frac{1}{X^2} \tag{3}$$

where $\frac{\partial p}{\partial z}F$ is the pressure gradient due to friction (N m^{-2} m^{-1}) and the subscript of tp is for two-phase flow, f for fluid and g is for gas. The Martinelli parameter, X, is given by the following equation:

$$X = \left[\frac{(-\frac{\partial p}{\partial z}F)_g}{(-\frac{\partial p}{\partial z}F)_f}\right]^{1/2} = \left[\frac{2f_f G^2(1-x)^2\rho_g/D}{2f_g G^2 x^2 \rho_f/D}\right] = \left(\frac{f_f}{f_g}\right)^{1/2}\left(\frac{1-x}{x}\right)\left(\frac{\rho_g}{\rho_f}\right)^{1/2} \tag{4}$$

The friction factor in Equation (4) was obtained by looking at laminar-turbulent flows, where $f = 16\,Re^{-1}$ for laminar flow (Re < 2300) and $f = 0.079\,Re^{-0.25}$ for turbulent flow (Re > 3000). For this study, Dittus and Boelter[15] correlation is used for turbulent flow with $Re_f \geq 5\,x\,10^6$.

$$h_{fo} = 0.023 Re_f^{\ 0.8} Pr_f^{\ 0.4} (\frac{k_f}{D}) \quad (5)$$

where k_f is the thermal conductivity of the fluid, Pr_f is Prandtl number for fluid. The structure for all the three correlations is the same except for the factor *F* and *S*, the general form of which are:

$$F = MAX\left[\left(a_1\left(\phi_f^2\right)^{a_2} + a_3\right), 1\right] \quad (6)$$

$$S = b_1(\phi_f^2)^{b_2} Bo^{b_3} \quad (7)$$

where *Bo* is the Boiling number, $Bo = \frac{q}{Gi_{fg}}$. The constants utilized by the three researchers are listed in Table 1.

TABLE 1. Comparisons of *F* factor and *S* factor between three correlations

Correlations	F factor	S factor
Pamitran et al.[10]	$a_1 = 0.009, a_2 = 2,$ $a_3 = 0.76$	$b_1 = 0.38, b_2 = -0.2093,$ $b_3 = 0.7402$
Oh et al.[9]	$a_1 = 0.023, a_2 = 1.1,$ $a_3 = 0.76$	$b_1 = 0.279, b_2 = -0.029,$ $b_3 = -0.098$
Choi et al.[8]	$a_1 = 0.007, a_2 = 1.15,$ $a_3 = 0.95$	$b_1 = 0.12, b_2 = 0.3421,$ $b_3 = 0.0469$

The parameters values in this study are taken based on the three authors; Oh et al. [9], Pamitran et al. [10] and Choi et al.[8].The values for all the variables needed for the fluid characteristics of R290 are at 10°C because the experimental data from these three authors are available at this saturated temperature. The values needed are shown in Table 2.

TABLE 2. The values of variables which are evaluated at 10°C of R290

Variables	Value
Mass flux, G(kg $m^{-2}s^{-2}$)	100
Heat flux, q(kW m^{-2})	15
Diameter,D (mm)	3
Vapour quality, *x*	0.009
Critical Pressure(MPa)	4.23
Density liquid(kg m^{-3})	514.73
Density gas(kg m^{-3})	13.783
Latent heat of vaporization(J/kg)	360.28 x 10^3
Prandtl number	2.8899
Saturation pressure(MPa)	0.637
Viscosity liquid	113.35 x 10^{-6}
Viscosity gas	7.7544 x 10^{-6}
Molar mass, M	44.1
Thermal heat conductivity(W/mK)	100.936 x 10^{-3}

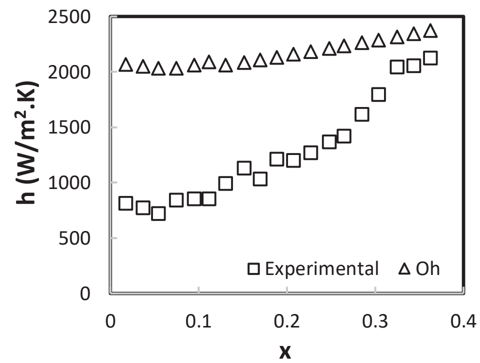
The first part of the study involves analyzing the possible regions of dryout expected from the three selected correlations. Comparisons are done at various values of mass flux (*G*), heat flux (*q*) and vapour quality (*x*). Then, optimization of the two mechanisms that contribute towards the two phase heat transfer coefficient is completed. This is to determine the conditions for optimum *G*, *q*, and *x* such that both nucleate boiling and forced convective are maximized simultaneously, achievable with Multiobjective Genetic Algorithm (MOGA).For this study, the correlation being selected is using Oh et al. [9] set of constants for *S* and *F* factor as in Table 1.

TABLE 3. Summary of boundaries for optimization

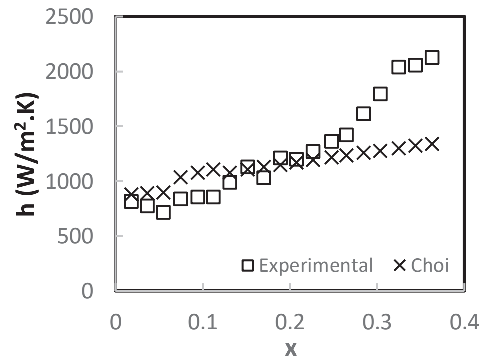
Parameters	Boundaries	Remarks
Mass flux, G	100-200 kg $m^{-2}s^{-2}$	Optimization is based on the constants of Oh's correlation.The number of iterations are limited to 200 of iterations.
Heat flux, q	5-20 kW m^{-2}	
Vapour quality, x	• $0.0<x<0.4$ • $0.0<x<0.8$ • $0.0<x<1.0$	

RESULTS AND DISCUSSIONS

The results of the graph patterns obtained for 5 kWm^{-2} is shown in Figure 1. It can be seen that both the experimental data and predicted coefficient agrees quite well in the trend for the three correlations up to vapor quality of 0.4. There is no drop in the value based on the three graphs in Figure 1, meaning no dryout occurred.



(a)



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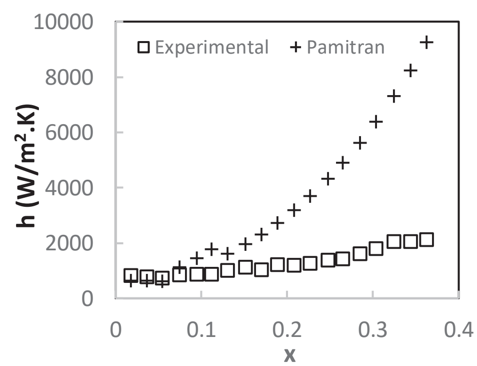


(c)

FIGURE 1. Comparison of variation of boiling heat transfer coefficient at heat flux of 5 kWm^{-2} (a) Oh et al.[9] (b) Choi et al.[8] (c) Pamitran et al. [10]

At 10 kW m^{-2} of heat flux, as shown in Figure 2, Oh et al. [9] correlation predicted very well the experimental data and it is developed earlier than the other two correlations. Pamitran et al. [10] graph does not seem good since the difference between experimental and predicted is huge. The occurrence of dryout at this stage can be seen at Choi et al. [8] and correlations only.

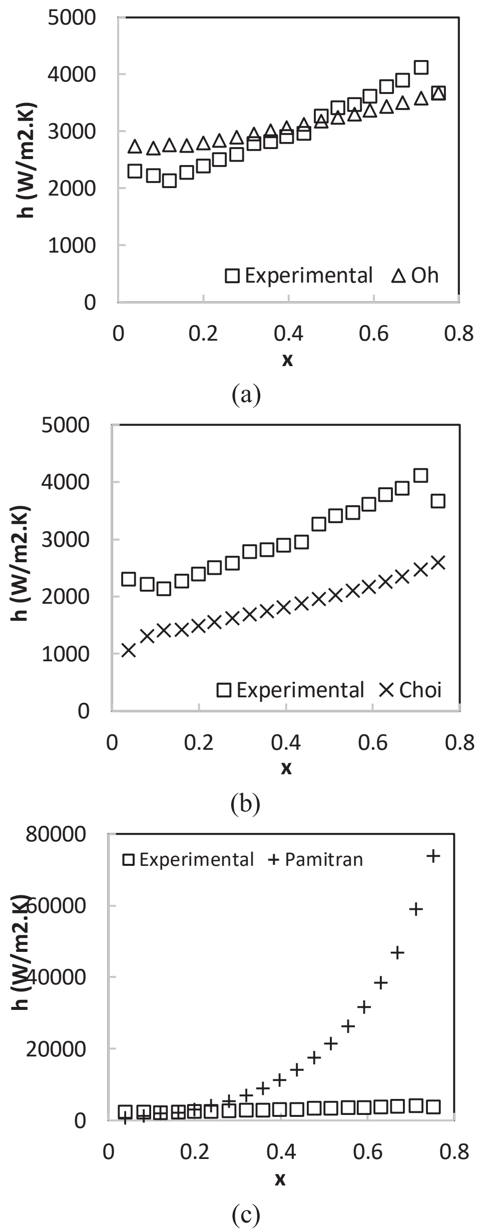
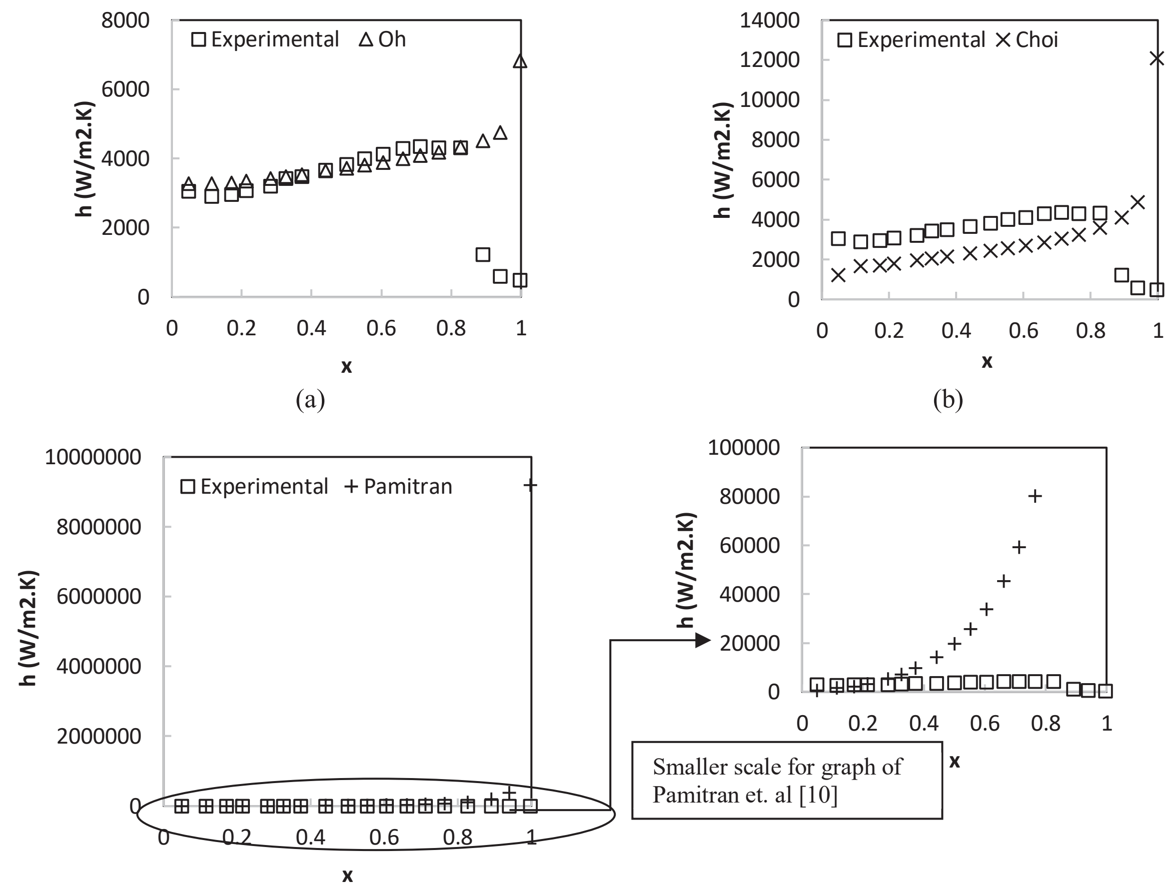


FIGURE 2. Comparison of variation of boiling heat transfer coefficient at heat flux of 10 kWm^{-2} (a) Oh et al.[9] (b) Choi et al.[8] (c) Pamitran et al. [10]

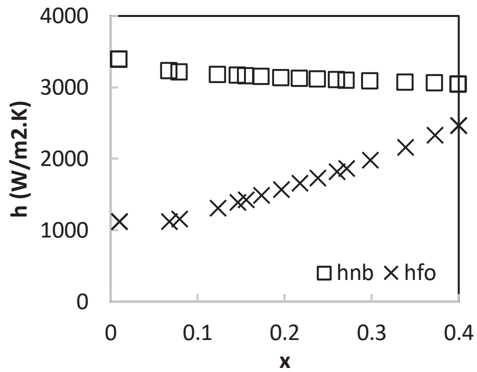
For the 15 kWm^{-2}, shown in Figure 3, the dryout occurrence can be seen in all experimental data. The predicted heat transfer coefficient peaks when the vapor quality is at or close to 1. Choi et al. [8] and Oh et al. [9] correlatios give a significant view of dryout occurrence where the experimental value of drops after vapor quality of 0.8. The three developed correlations did not predict well the presence of dryout.



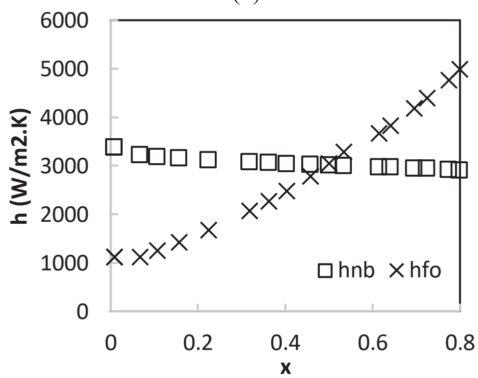
(c)

FIGURE 3. Comparison of variation of boiling heat transfer coefficient at heat flux of 15 kWm^{-2} (a) Oh et al.[9] (b) Choi et al.[8] (c) Pamitran et al. [10]

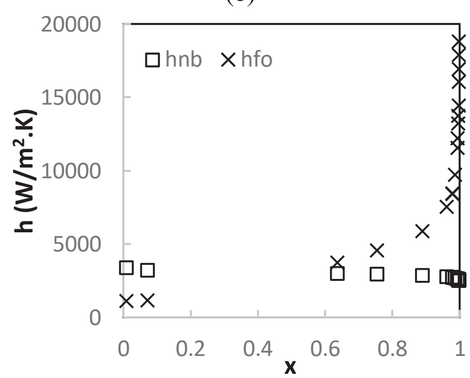
Next, the optimization is done by using Multiobjective Genetic Algorithm (MOGA). The results of the optimization are shown in Figure 4. Here, the nucleate boiling and forced convective heat transfer contributions are shown individually under the optimized condition towards the total two-phase heat transfer coefficient. Based on Figure 4, the intersection of nucleate boiling and forced convective happens when the optimized condition is at vapor quality within the range of 0.0 until 0.8 as clearly shown in Figure 4(b) and somewhat interpolated in Figure 4(c). Figure 4(a) shows no intersection between nucleate boiling and forced convective, the range did not include the dryout region. Yunos et al. [4] claimed that in the superposition correlation, the intersection between nucleate boiling and forced convective is significantly shown at certain point of vapor quality. Nucleate boiling is contributing significantly at low vapor quality, while forced convective's contribution is at high vapor quality. The total two-phase heat transfer coefficient shows the decrease turnout point at the intersection point, which is possibly the starting point for the dryout condition in channel flow heat transfer. Since only Figure 4(b) clearly indicates the intersection, possible dryout occurred for R290 investigated here is at vapor quality of 0.5, under optimized condition. MOGA determines the dryout clearly when the boundaries take the range of vapor quality between 0.0 until 0.8. Thus, by using MOGA, it showed that when the mass flux, G is around 200 $kgm^{-2}s^{-2}$, heat flux, q is around 19 kW m^{-2}, the vapour quality range must be taken into account which is between 0.0 until 0.8. Dryout can be predicted and operating under conditions after this region will not be desirable with lower heat transfer capacity.



(a)



(b)



(c)

FIGURE 4. The contribution of nucleate boiling and forced convective under optimized conditions. (a) $0.0<x<0.4$ (b) $0.0<x<0.8$(c) $0.0<x<1.0$

CONCLUSION

This study has shown the effect near the dryout region towards boiling heat transfer coefficient. Analysis of the selected three correlations of Oh et al.[9] , Pamitran et al.[10] and Choi et al.[8] have shown that even with later developments in the heat transfer coefficient, disagreements between experimental data and predicted values are much higher than those developed earlier. Analysis of the three correlations of Oh et al.[9] , Pamitran et al. [10] and Choi et al. [8] indicate that the area of disagreement occur as the vapour quality approaches 0.6 to 0.8. Optimization of the heat flux, mass flux, and vapour quality to maximize both the nucleate boiling and forced convective contributions simultaneously, using MOGA have shown the ability of MOGA to identify the intersection of both mechanisms where dryout is supposed to occur. This can be a guide to controlling the heat exchanging devices such that operations are within the bounds for the desired maximum heat transfer.

It is recommended to further continue the study on the factor of dryout region in boiling in more details. Correlations developed should take into account the effect near the dryout region to possibly attain better accuracy than they are now.

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REFERENCES

1. R.K Shah , Classification of heat exchangers. In: Kakac S, Bergles A E, Mayinger F. (Eds.), *Heat Exchangers: Thermal Hydraulic Fundamentals and Design*. Hemisphere Publishing Corp., Washington DC, (1986) 9–46
2. S.S Mehendale, A. M Jacobi and R.K Shan, Appl. Mech. Rev. **53** (7) (2000) 175–193
3. J.G Collier and J.R Thome *Convective Boiling and Condensation*, New York: Oxford University Press 1994
4. Y.M Yunos,N.M Ghazali,M Mohamad,A.S Pamitran,J.T Oh, Int. J. Air-Condition. Refrig., **26** (1)(2018).
5. Z. Liu and R.H.S Winterton, Int. J. Heat Mass Transfer **34** (1991) 2759-2766
6. S.S Bertsch, E.A Groll, S.V Garimella, Int. J. Heat Mass Transfer **52** (2009) 2110-2118.
7. M.M Mahmoud and T.G Karayiannis, Int. J. Heat Mass Transfer **66** (2013) 553-574.
8. K.I Choi, J.T Oh, K Saito, J.S Jeong, Int. J. Refrigeration **41**(2014) 210-218.
9. J.T Oh, A.S Pamitran, K.I Choi, P Hrnjak, Int. J. Heat Mass Transfer **54** (2011) 2080-2088.
10. A.S Pamitran, K.I Choi, J.T Oh, Nasruddin, Int. J. Multiphase Flow **37**(2011) 794-801.
11. M.G Cooper, Adv.Heat Transfer **16**, (1984) 157-239.
12. W Zhang, T Hibiki and K Mishima, Int. J. Heat Mass Transfer **47** (2004) 5749–5763
13. D Chisholm, Int. J. Heat Mass Transfer **10** (1967) 1767–1778.
14. C.Y Yang and T.Y Lin, Exp. Therm. Fluid Sci. **32** (2) (2007) 432–439.
15. F.W. Dittus and L.M.K Boelter, *Heat Transfer in Automobile Radiators of the Tubular Type*, University of California Publication in Engineering, Vol. 2, (1930). 443–461.
16. J. Heo, H. Lee and R. Yun, Int. J. Air-Condition. Refrig. **21** (2013) 1-14.