A STUDY ON THE CRITICAL HEAT FLUX TEMPERATURE

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A boiling curve has a functional relationship between the transferred heat flux and surface temperature of the heated wall. The maximum heat flux is usually called Critical Heat Flux in a boiling curve. Critical Heat Flux (CHF) is the maximum rate of thermal energy that can be transferred per surface area. Dryout and departure from nucleate boiling (DNB) distinguish two types of Critical Heat Flux associated with different speeds of the temperature rise followed by burnout. The Critical Heat Flux temperature is also called temperature for departure from nucleate boiling, burnout temperature.

Critical Heat Flux and the Critical Heat Flux temperature have been measured with a test section, which was made of Inconel 600 and designed with 8 mm OD, 170 mm length and 1 mm wall thickness. Two flanges have been welded directly to the ends of the tube and served as power clamps for the electrical power supply unit (15V, 2500A, DC). The wall temperature of the test section was detected using ten thermocouples fixed with laser weld onto the outer tube wall. During the measurements, the heating power at the test section was carefully increased with time, until CHF was reached and the power to the test section was switched off as soon as one of the thermocouples fixed onto the tube perceived a rise in the wall temperature beyond a present value due to exceeding the peak of removable heat flux.

In fact, the measurements were carried out in a vertical tube at up flow with water at mass flow rates of 50-400 kg/m^{2}s at low pressure (1.0-7.0 bar) and subcooling up to 70 K. However, in this study the results that were obtained at atmospheric pressure for mass flow rates of 300-400 kg/m^{2}s will be discussed. Dryout generally occurs at the outlet of the test section. However, it has also been observed that the temperature initially rises in the middle of the tube at atmospheric pressure for mass flow rates of 300-400 kg/m^{2}s.

Wall temperatures can be used to determine flow characteristics. There are some models such as by Schroeder-Richter and Bartsch (1994), Thom et al. (1965), Weber (1990) and Carbajo (1985).
Schroeder-Richter & Bartsch (1994) have obtained a model prediction the wall temperature corresponding to CHF. They reported their model was based on bubble models and thus predicts DND (Departure from Nucleate Boiling) rather than dryout mechanism. The following expression is given by Schroeder-Richter & Bartsch (1994) for water:

$$T_{DNB} = \frac{T_s}{1 - 0{,}6\,\frac{T_s}{h_{fg}}\,\frac{kj}{kgK}} \tag{1}$$

Thom et al. (1965) proposed the following prediction model:

$$\Delta T_{CHF} = 0{,}0081\,e^{-p/8{,}7}\left[\rho_g^{\,1/2} h_{fg} \left(g\sigma(\rho_l - \rho_g)\right)^{1/4}\right]^{1/2} \tag{2}$$

Eq.(2) was developed from water data in the pressure range of 6,9 to 172,3 bar. However, it may be extended to lower pressures.

Carbajo (1985) proposed for pressure up to 0,4 MPa the following expression:

$$T_{CHF} = 195,7P + 110 \text{ (°C)} \tag{3}$$

The following prediction model has been developed by Weber (1990). The wall superheat depends on not only pressure also mass flux too.

$$\Delta T_{CHF} = 31,3.e^{\left[-26,45\left[\frac{\rho_g}{\rho_l}\right]+0,0057\ G^*-1,81\ x_E\right]} \tag{4}$$

$$G^* = \frac{G}{\rho_g^{1/2}\left(g\sigma\left(\rho_l-\rho_g\right)\right)^{1/4}} \tag{4a}$$

A comparison of different correlations is presented in figure 1. This figure shows that all of the prediction models tend to increase in wall superheat at CHF except Weber prediction (Eq.4). Our measured data is obtained at mass flux of 300 kg/m^{2}s shows a good agreement with Weber prediction (Eq.4). Weber correlation is calculated for a mass flow rate of 300 kg/m^{2}s in figure 1.

Another way to identify flow pattern is to show data in a diagram CHF versus critical quality. It is observed that CHF occurred at the some parameter in the middle of the test section or closer to the inlet of the tube.

Figure 2a shows that CHF occurs for the mass flow rate 400 kg/m^{2}s in the middle of the test section at atmospheric pressure but at 7 bar at the end of the test section (fig.2b).

Figure 3a shows CHF occurs only for low subcooling in the middle of the test tube at pressure of 1 bar for the mass flow rate 300 kg/m^{2}s but at 7 bar at the end of the tube (Fig.3b).

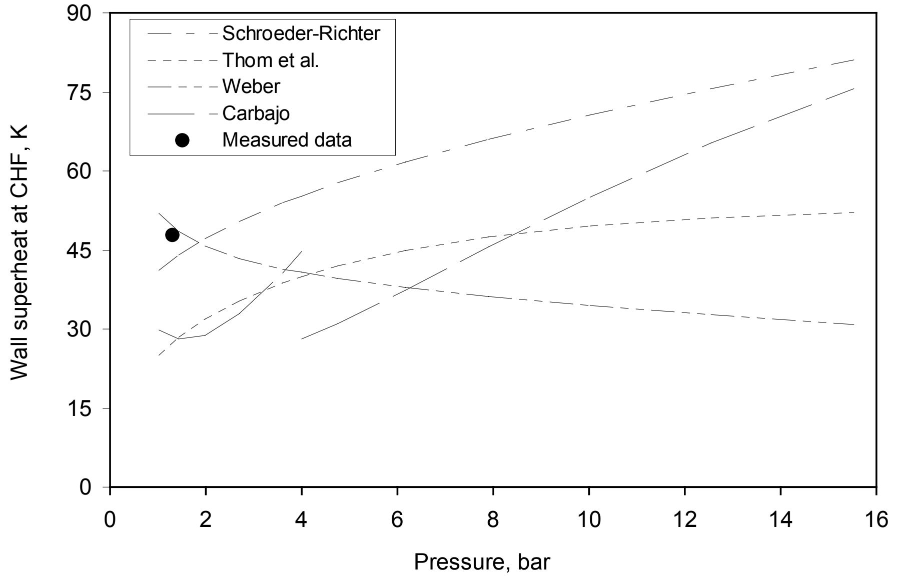
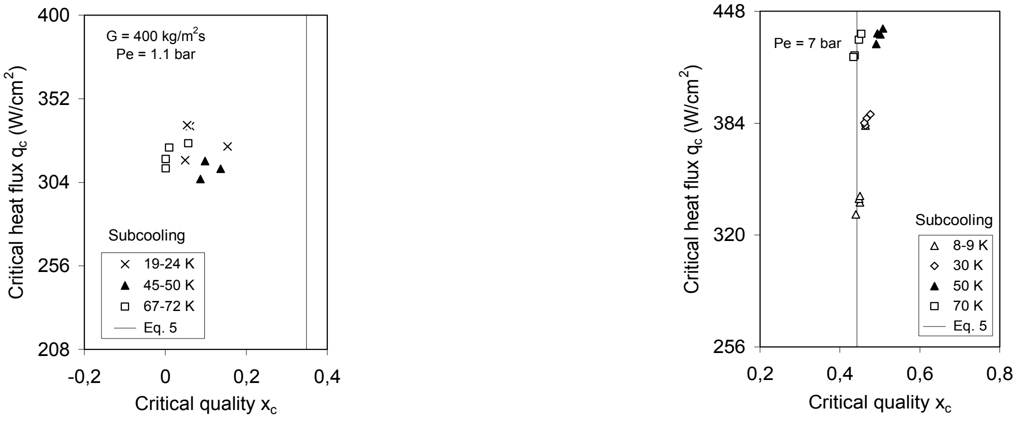
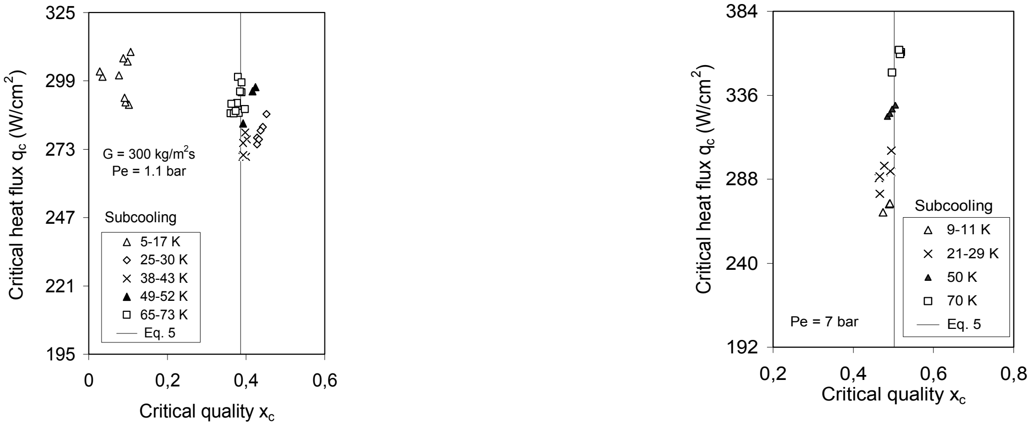


Figure 1: Pressure dependence of wall superheat at critical heat flux.



(a) (b)

Figure 2: CHF versus critical quality at G=400 kg/m^{2}s



(a) (b)

Figure 3: CHF versus critical quality at G=300 kg/m^2

Figure 2b and 3b show data that CHF observed at pressure of 7 bar at the end of the test section. The CHF data versus critical quality tend to be vertical which is defined limiting quality phenomenon. In the figure 2 and 3 Eq.5 is a correlation for the limiting quality at CHF is given by Yildiz (1998) following:

$$x_l = \frac{0.291}{9.85F(P)\left[\frac{G}{1000}\left(\frac{1}{kg/m^2s}\right)\right]^{1.39}+0.39}+0.255 \tag{5}$$

$$F(P) = 0.0199 + 0.00047\left(\frac{1}{bar}\right)P + 0.987\exp\left(-0.018\left(\frac{1}{bar^2}\right)P^2\right) \tag{5a}$$

In the case, CHF occurred in the middle of the test section or closer to the inlet of the tube, the inside wall temperature of the test section has been calculated, because we measured the outside wall temperature of the tube.

A model by Schroeder Richter and Bartsch (1994) has been compared with the temperature measured. The inner wall temperature shows a good agreement with the predicted wall temperature DNB. The CHF temperatures from our measurements, which have been observed in the middle of the test section or closer to the inlet of the test section are also compared with the other CHF temperature models in literature, such as Carbajo (1985) and Weber (1990). Carbajo correlation (Eq.3) shows a disagreement with our data. However, Weber correlation (Eq.4) also shows relative close to Eq.1. Unfortunately, we do not have CHF data except at the atmospheric pressure, which are observed in the middle of the tube or closer to inlet them.

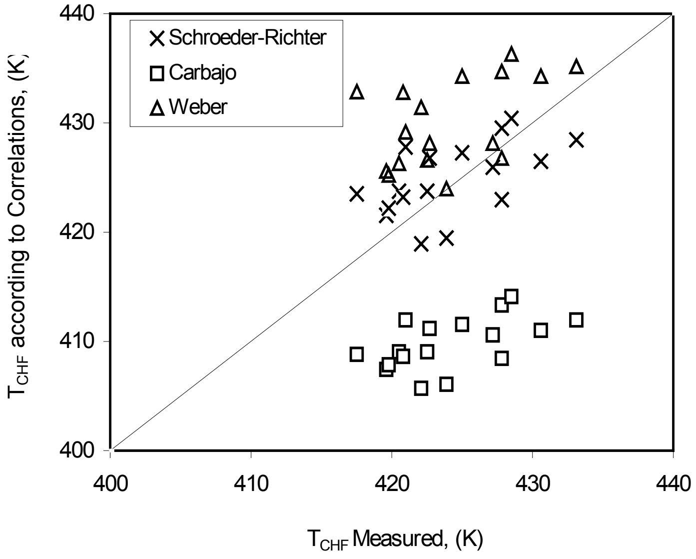


Figure 4: Comparison of the measured CHF temperature with the correlation.

Figure 5 shows dependence of wall superheat at CHF on subcooling for the mass flux 300 kg/m^{2}s. Both Weber (1990) and Schroeder-Richter & Bartsch (1994) correlations show a good agreement. But Carbajo (1985) predicted critical heat flux temperature lower than other.

In this study measurements were repeated at least three times for every experimental parameter to be precise.

The results will be discussed in more detail.

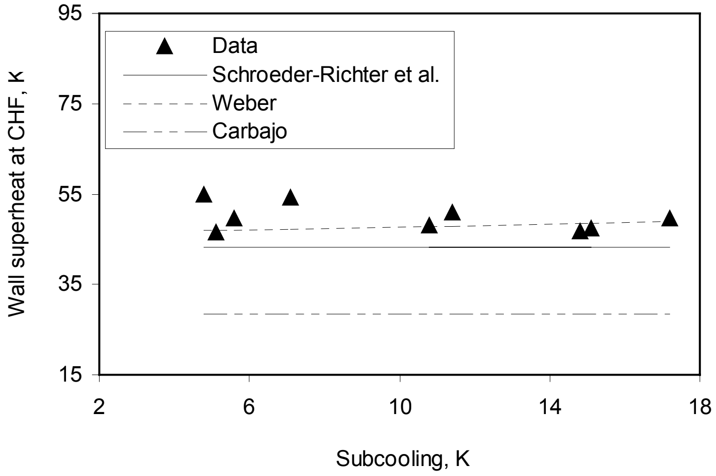


Figure 5: Wall superheat at critical heat flux versus subcooling for the mass flux 300 kg/m^{2}s.

KEYS: CHF Temperature, DNB, up flow, water

NOMENCLATURE

CHF	critical heat flux
DNB	departure from nucleate boiling
G	mass flux, mass flow rate, kg/m^{2}s
h	enthalpy, J/kg
h_{fg}	latent heat of vaporization, J/kg, kJ/kg
P	pressure, bar
q	heat flux, (W/cm^2)
x_l	limiting quality
T	temperature, K, °C
σ	surface tension
ρ	density, kg/m^3
g	gravitational acceleration m/s^2
x	quality

Subscripts

c	critical
l	liquid
g	gase
s	saturated
E	exit

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