Experimental Evaluation of Constants for the Rohsenow Pool Boiling Correlation for Khoa

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ABSTRACT

The present study is carried out to determine the fluid-surface constant for Rohsenow pool boiling correlation during khoa making in an aluminum and stainless steel pots. The experimental data collected were analyzed and correlation similar to Rohsenow pool boiling was developed for khoa. The average values of constant 'C_{sf}' for Rohsenow correlation for aluminum and stainless steel surfaces were found to be 7.8815 x 10^{-3} and 9.4772 x 10^{-3} respectively.

Keywords: *Khoa, khoa making, pool boiling, rohsenow pool boiling correlation.*

1. INTRODUCTION

BOILING is a liquid to vapor phase change process which occurs when the wall temperature of the heated surface is sufficiently above than the saturation temperature of the liquid. Boiling under quiescent fluid conditions is termed as pool boiling. During the last 70 years, pool boiling heat transfer has been investigated by many researchers worldwide [1-8]. Rohsenow proposed constant values of the exponents in dimensionless numbers and provided a list of values of 'C_{sf}' for some surface-fluid combinations which was further extended by Vachon et. al, . Rohsenow pool boiling correlation has also been evaluated experimentally by many researchers at sub-atmospheric, atmospheric, or higher pressure. Tiwari et al., [9] have evaluated the convective heat and mass transfer coefficient under pool boiling condition for sugarcane juice during preparation of jaggery. The heat transfer coefficients were reported to vary from 50.65 to 345.20 W/m^2 ^{0}C for heat inputs ranging from 160 to 340 W.

The milk is heated and boiled during manufacturing of khoa. Khoa is widely used as base material for the preparation of various sweetmeats. Recently, Kumar et al., [10, 11] have experimentally studied the pool boiling of milk in an aluminum and stainless steel pan under open conditions for khoa production by conventional heating method by varying the heat inputs from 240 to 360 W. Kumar et al., [12] evaluated the convective heat transfer coefficients for pool boiling of milk in an aluminum pan under closed conditions. The convective heat transfer coefficients were reported to vary from 186.32 to 567.56 W/m^2 ^{0}C for the heat inputs varying from 240 to 360 W. The nucleate boiling heat flux was observed to increase exponentially with the increase in excess temperature.

The present study has been set forth to determine the values of the constants 'C_{sf}' for Rohsenow correlation during khoa making in an aluminum and stainless steel pots. The collected data has been analyzed and equation similar to Rohsenow pool boiling correlation has been developed for khoa. The information will be useful in designing an evaporator for khoa production, which will make the khoa manufacturing process efficient and economical. The values of the constant 'C_{sf}' for various fluid-surface combinations are given below [13-15]: Water-copper (polished): 0.0130; Water-copper (scored): 0.0068; Water-stainless steel (mechanically polished): 0.0130;

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Water-stainless steel (ground and polished): 0.0060; Water-stainless steel (Teflon pitted): 0.0058; Water-stainless steel (chemically etched): 0.0130; Water-brass: 0.0060; Water-nickle: 0.0060; Water-platinum: 0.0130; n-Pentane-copper (polished): 0.0154; Benzene-chromium: 0.1010; Ethyl alcohol-chromium: 0.0027; Carbonate tetrachloride-copper: 0.0130; Isopropanol-copper: 0.0025; Ghee-stainless steel: 2.557×10^{-4}.

2. EXPERIMENTAL DETAILS AND PROCEDURE

The schematic diagram of the experimental set-up is shown in Fig. 1. It consists of a hot plate of 1000W capacity connected through a variac to control the rate of heating of the milk in a pot of capacity 3.2 liters. The heat input was measured by a calibrated wattmeter (accuracy within ±0.5% of full scale value 1500 watts), having a least count of 1 watt. Calibrated copper-constantan thermocouples connected to a ten channel digital temperature indicator (least count of 0.1 ^{0}C, accuracy ± 0.1%, and range of 50 to 200 ^{0}C) were used to measure the temperature of the milk (T_1) and the surface temperature of the pot at the bottom (T_2).

The fresh milk sample obtained from a herd of 15 cows was heated in an aluminum and stainless steel cylindrical pot (200 mm in diameter, 102 mm deep and 1.6 mm thick) without any cover for different values of heat inputs ranging from 240 to 360 watts. The experiments follow a path of increasing heat inputs. For each run of the test, fresh sample of milk was taken from the same herd of cows. In traditional method of khoa making, milk is heated in an open pan and simultaneously it is stirred and scraped with a palta (iron scraper) to prevent the scorching of milk solids sticking to the pan. In the present research work, light manual stirring and scraping of milk has been carried out with the help of a Teflon scraper to avoid the scaling and burning of the product. Skin formed at the milk surface has been broken by stirring the milk gently at frequent intervals. Different sets of heating of milk have been obtained by varying the input power supply from 240 to 360 watts to the electric hot plate with the help of the variac. The experimental results for different sets of heating are reported in Tables 1-2.

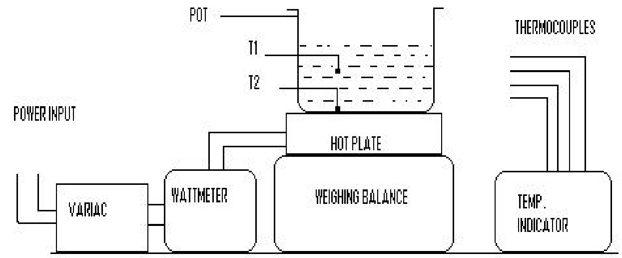

Fig.1: Schematic view of experimental unit

3. RESULTS AND DISCUSSION

Various indoor experiments have been conducted for pool boiling of milk during khoa making in aluminum and stainless steel pots at different heat inputs of 240, 280, 320 and 360 watts. The details of the nucleate boiling heat flux values used for determining the constant 'C_{sf}' are given elsewhere . In 1952, Rohsenow proposed the following correlation equation for pool boiling heat transfer:

$$C_{pl}\left[\frac{\Delta T}{h_{fg}\Pr^n}\right] = C_{sf}\left[\frac{q_{nucleate}}{\mu_l h_{fg}}\sqrt{\frac{\sigma}{g(\rho_l-\rho_v)}}\right]^{\frac{1}{3}}$$

This equation is widely regarded as being the best nucleate pool boiling equation that is available today, and it is widely published. This equation can also be written as

$A = C_{sf}.B$ where $A = C_{pl}\left[\frac{\Delta T}{h_{fg}\Pr^n}\right]$ and

$$B = \left[\frac{q_{nucleate}}{\mu_l h_{fg}}\sqrt{\frac{\sigma}{g(\rho_l-\rho_v)}}\right]^{\frac{1}{3}}$$

Thus the value of 'C_{sf} is given by $C_{sf} = A/B$

The thermal physical properties of milk are evaluated at the saturation temperature of the milk by using the expressions given in Appendix-I. The power of Prandtl number has been taken as 1.7 as suggested by Rohsenow. The values of constant 'C_{sf}' for Rohsenow correlation during khoa making in an aluminum pot were determined, which varied from 0.006531 to 0.009071 whereas for stainless steel pot it was observed to vary 0.007565 to 0.011474. These

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results are given in Tables 1-2. Thus the average values of 'C_{sf}' for aluminum and stainless steel pot surfaces were evaluated as 7.8815 x 10^{-3} and 9.4772 x 10^{-3} and respectively. After determining the values of 'C_{sf}' the convective heat transfer coefficients for khoa making in aluminum and steel pots were also determined. In the case of aluminum pot it was observed to vary from 395.58 to 1055.84 W/m^2 ^{0}C and for stainless steel pot it varies from 317.53 to1007.63 W/m^2 ^{0}C. It is observed that the convective heat transfer coefficient for khoa strongly depends on the heat inputs and was found to increase significantly with the increase in heat inputs. These results are in accordance with those reported in the literature .

Table 1(a) : Experimental values and thermal properties for khoa in an aluminum pot

Heat input (W)	ΔT	μ_l (kg/m. s)	C_{pl} (J/kg °C)	k_l (W/m^2 °C)	σ (N/m)	ρ_l (kg/m^3)	ρ_v (kg/m^3))	h_{fg} (J/kg)	$\Pr_l$
240	9.8	0.000531	3956.864	0.474019	0.042591	997.5656	0.97595	1606264	4.43428
280	10.1	0.000533	3955.674	0.478873	0.042571	998.8116	0.97703	1638140	4.41058
320	9.7	0.000531	3956.566	0.494972	0.042532	998.6091	0.97622	1740835	4.25338
360	9.6	0.000534	3955.376	0.499903	0.042584	998.879	0.977298	1773265	4.23572

Table 1(b) : Rohsenow type Correlation for khoa in an aluminum pot

Heat input (W)	$q_{nucleate}$ (W/m^2)	$A = C_{pl}\left[\dfrac{\Delta T}{h_{fg}\,\Pr_l^{1.7}}\right]$	$B = \left[\dfrac{q_{nucleate}}{\mu_l h_{fg}}\sqrt{\dfrac{\sigma}{g(\rho_l-\rho_v)}}\right]^{1/3}$	$C_{sf} = \dfrac{A}{B}$
240	3876.689	0.001919	0.211598	0.009071
280	5360.753	0.001957	0.233945	0.008364
320	6833.453	0.001881	0.248853	0.007560
360	10159.51	0.001840	0.281796	0.006531

Table 2(a) : Experimental values and thermal properties for khoa in a stainless steel pot

Heat input (W)	ΔT	μ_l (kg/m. s)	C_{pl} (J/kg °C)	k_l (W/m^2 °C)	σ (N/m)	ρ_l (kg/m^3)	ρ_v (kg/m^3))	h_{fg} (J/kg)	$\Pr_l$
240	12.2	0.000525	3959.245	0.475903	0.042414	997.999	0.973798	1617978	4.37349
280	12.4	0.000523	3960.435	0.484916	0.042362	997.7267	0.972726	1673857	4.27372
320	12.0	0.000523	3960.435	0.486685	0.042362	997.7267	0.972726	1685189	4.26312
360	11.1	0.000521	3961.328	0.497487	0.042323	997.522	0.971923	1753767	4.15545

Table 2(b) : Rohsenow type Correlation for khoa in a stainless teel pot

Heat input (W)	$q_{nucleate}$ (W/m^2)	$A = C_{pl}\left[\dfrac{\Delta T}{h_{fg}\,\Pr_l^{1.7}}\right]$	$B = \left[\dfrac{q_{nucleate}}{\mu_l h_{fg}}\sqrt{\dfrac{\sigma}{g(\rho_l-\rho_v)}}\right]^{1/3}$	$C_{sf} = \dfrac{A}{B}$
240	3873.847	0.002429	0.211767	0.011474
280	6175.018	0.002484	0.244865	0.010143
320	8778.341	0.002397	0.274709	0.008727
360	11184.66	0.002226	0.294265	0.007565

Nomenclature

C_{pl}	Specific heat, J/kg ^{o}C
C_{sf}	Experimental constant that depends on surface-fluid combination
g	Gravitational acceleration, m/s^2
h_{fg}	Enthalpy of vaporization, J/kg
k_l	Thermal conductivity of milk, W/m ^{o}C
n	Experimental constant that depends on fluid
$\Pr_l = \dfrac{\mu_l C_{pl}}{k_l}$	Prandtl number of the liquid
$q_{nucleate}$	Nucleate boiling heat flux, W/m^2
T_s	Average surface temperature, ^{o}C
T_{sat}	Saturation temperature, ^{o}C
$\Delta T = T_s - T_{sat}$	Excess temperature
μ_l	Viscosity of milk, kg/m.s
ρ_l	Density of milk, kg/m^3
ρ_v	Density of vapor, kg/m^3
σ	Surface tension of milk, N/m

REFERENCES

[1] Rohsenow W M, A method of correlating heat transfer data for surface boiling of liquids, Trans ASME, 74, 1952, pp 969-976.

[2] Berenson P J, Experiments on pool boiling heat transfer, International J Heat Mass Transfer, 5, 1962, pp 985-999.

[3] Vachon R I, Nix G H & Tanger G E, Evaluation of constants for Rohsenow pool boiling correlation, Journal of Heat Transfer, 90, 1968, pp 239-247.

[4] Labuntsov D A, Heat transfer problems with nucleate boiling of liquids, Thermal Engineering, 9, 1972, pp 21-28.

[5] Sauer, J H J, Medrow, R A & Sinnarwalla, A M, Effects of surface condition on nucleate boiling of refrigerant-11, ASHRAE Transactions, 81(2), 1975, pp 274-280.

[6] Lal G & Verma R D, Evaluation of constants for Rohsenow pool boiling correlation for ghee, Indian J. Dairy Sci., 40(4), 1987, pp 431-434.

[7] Pioro I L, Experimental evaluation of constants for the Rohsenow pool boiling correlation, International J Heat Mass Transfer, 42, 1999, pp 2003-2013.

[8] Jabardo J M S, Silva E F D, Ribatski G & Barros, S F D, Evaluation of the Rohsenow correlation through experimental pool boiling of halocarbon refrigerants on cylindrical surfaces, J. of the Braz. Soc. of Mech. Sci. and Eng., 26(2), 2004, pp 218-230.

[9] Tiwari GN, Prakash O & Kumar S, Evaluation of convective heat and mass transfer for pool boiling of sugarcane juice, Energy Conversion and Management, Vol. 45, 2004, pp171-179.

[10] Kumar M, Prakash O & Kasana KS, An experimental study on pool boiling of milk, Heat transfer - Asian research, 40(2), 2011, pp 159-170.

[11] Kumar M, Prakash O & Kasana KS, Experimental study on pool boiling heat transfer coefficient of milk, The Scientific journal Facta Universitatis series Mechanical Engineering, Accepted (Feb. 2011).

[12] Kumar M, Kasana KS, Kumar S & Prakash O, Evaluation of convective heat transfer coefficient for pool boiling of milk under closed condition, S-JPSET, Vol. 1(2), 2010, pp 91-99.

[13] Cengel YA, 2002, Heat transfer-a practical approach, Tata McGraw-Hill Publishing Company Limited, New Delhi, pp 460.

[14] Incropera FP & Dewitt DP, 2010, Fundamentals of heat and mass transfer, John Willey & Sons, USA, pp 602.

[15] Bejan A & Kraus AD, 2003, Heat Transfer Handbook, John Willey & Sons, USA, pp 654.

APPENDIX-I

The following expressions were used for calculating the different thermal physical properties of milk such as specific heat (C_{pl}), surface tension (σ), density (ρ_l), viscosity (μ_l), thermal conductivity (k_l), and enthalpy of vaporization (h_{fg}) [10-12]:

$$C_{pl} = 2.976T + 3692 \tag{1}$$

$$\sigma = 1.8 \times 10^{-4} T^2 - 0.163T + 55.6 \tag{2}$$

where σ is in N.m^{-1}×10^{-3}

$$\begin{aligned}\rho_l = {} & -0.2307 \times 10^{-2} T^2 - 0.2655T + 1040.51 \\ & - F(-0.478 \times 10^{-4} T^2 + 0.969 \times 10^{-2} T + 0.967)\end{aligned} \tag{3}$$

where F is the fat content percentage.

$$\ln \mu_l = 4.03 \times 10^{-5} T^2 - 2 \times 10^{-2} T + 0.827 \tag{4}$$

Where μ_l is in Pa.s ×10^{-3}

$$k_l = 0.356439 \bar{X}_w + 0.223544 \tag{5}$$

where $\bar{X}_w$ is the average water content %.

$$h_{fg} = (h_{fg}\ of\ water) \times \bar{X}_w \tag{6}$$