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RESEARCH ARTICLE

CONVECTIVE HEAT TRANSFER ENHANCEMENT BY INTERNAL HEATING OF SUGARCANE JUICE

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ABSTRACT

In this research paper, the experimental study on internal heating of sugarcane juice for sensible mode during jaggery making in an aluminum pot for the heat inputs varying from 200 to 360 W has been reported. The experimental data were used to determine the values of the constants in the Nusselt number by simple linear regression analysis and consequently, the convective heat transfer coefficients were determined. Its values were observed to vary from 2.98 to 6.00 W/m^2 ^{o}C for the given range of heat inputs. The convective heat transfer coefficients enhancement was observed in comparison to external heating.

Key words: Sugarcane juice; Jaggery making; Sensible heating; Convective heat transfer coefficient

INTRODUCTION

Dunkle (1961) and Cooper (1970) developed expressions to determine the rate of evaporation for distillation under indoor conditions with few limitations. Later on various researchers attempted to develop the model without any limitations for indoor as well as outdoor conditions. Thermal models were developed by Kumar and Tiwari (1996) and Tiwari *et al*. (1997) for heat and mass transfer without any limitations by linear regression analysis. Tiwari *et al*. (2003) reported the effect of varying voltage and mass on heat and mass transfer of sugarcane juice during natural convection heating in an aluminum pot for external heating. Kumar *et al*. (2012) experimentally determined the convective heat transfer coefficients of milk during khoa making which were found to vary between 3.00 to 6.01 W/m^2 ^{o}C. Recently, Kumar *et al*. (2011) reported the performance of stainless steel and aluminum pot surfaces for external heating during sensible mode of sugarcane juice for constant mass by varying heat inputs from 200 W to 360 W.

The sugarcane juice heating process during jaggery making involves natural and boiling convection heat transfer mechanisms. In this research paper, the effect of internal heating on natural convection (sensible) behavior of sugarcane juice during jaggery making in an aluminum pot has been reported. Various indoor experiments have been carried out for constant mass of the juice by varying heat inputs from 200 W to 360 W. The sensible heating of sugarcane juice is considered up to 90 ^{o}C (Tiwari *et al*., 2003; Kumar *et al*., 2011).

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Experimental Set-Up and Procedure

The schematic view of the experimental unit is shown in Fig. 1. It consists of an aluminum pot fitted with a spiral shaped aluminum immersion rod. The rate of heating of the sugarcane juice is controlled by a variac. The temperatures of heating rod surface (T_1) and Juice (T_2) were measured by a digital temperature indicator (least count of 0.1^{o}C) with calibrated thermocouples. The relative humidity (γ) and temperature above the juice surface (T_3) were measured by a digital hygrometer (model Lutron-HT3006 HA). The heat input was measured by a digital wattmeter having a least count of 1 watt. An electronic weighing balance (capacity 6 kg; Scaletech, model TJ-6000) with a least count of 0.1g was used to measure the mass of water evaporated during heating of the juice.

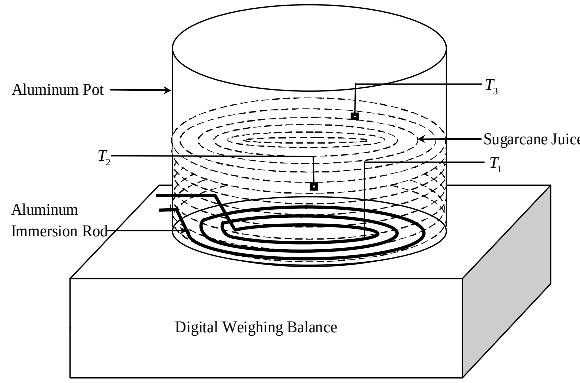

Fig. 1: Schematic view of experimental unit for internal heating of sugarcane juice

Sugarcane juice was heated in an aluminum pot (200 mm in diameter, 102 mm deep and 1.6 mm thick) for different heat inputs varying from 200 W to 360 W. The experimental data were recorded after every 10 minute time interval. Different sets of heating of sugarcane juice were obtained by varying the input power supply. For each run of the experimentation, constant mass of the sugarcane juice was taken i.e. 2200 g. The mass evaporated during heating of sugarcane juice were obtained by subtracting two consecutive readings in a given time interval. The experimental data for sugarcane juice heating are reported Tables 1-5.

Computation Procedure

The heat transfer coefficient for sensible heating of sugarcane juice was determined by using the following expression [8]:

$$Nu = \frac{h_c X}{K_v} = C(Gr\Pr)^n \quad \text{Or}$$

$$h_c = \frac{K_v}{X} C(Gr\Pr)^n \tag{1}$$

The rate of heat utilized to evaporate moisture is given as

$$\dot{Q}_e = 0.016 h_c \left[P(T_c) - \gamma P(T_e)\right] \tag{2}$$

($T_c = T_2$ *and* $T_e = T_3$ Used from Tables 1-5)

On substituting h_c from Eq. (1), Eq. (2) becomes

$$\dot{Q}_e = 0.016 \frac{K_v}{X} C(Gr\Pr)^n \left[P(T_c) - \gamma P(T_e)\right] \tag{3}$$

The moisture evaporated is determined by dividing Eq. (3) by latent heat of vaporization (λ) and multiplying the area of pan (A_p) and time interval (t).

$$m_{ev} = \frac{\dot{Q}_e}{\lambda} A_p t = 0.016 \frac{K_v}{X\lambda} C(Gr\Pr)^n \left[P(T_c) - \gamma P(T_e)\right] A_p t \tag{4}$$

Let

$$0.016 \frac{K_v}{X\lambda} \left[P(T_c) - \gamma P(T_e)\right] A_p t = K$$

$$\frac{m_{ev}}{K} = C(Gr\Pr)^n \tag{5}$$

Taking the logarithm of both sides of Eq. (5),

$$\ln\left[\frac{m_{ev}}{K}\right] = \ln C + n \ln(Gr\Pr) \tag{6}$$

This is the form of a linear equation,

$$y = mx + c \tag{7}$$

Where

$$y = \ln\left[\frac{m_{ev}}{K}\right], m = n,\ x = \ln(Gr\Pr) \text{ and } c = \ln C$$

Values of m and c in Eq. (7) are obtained by using the simple linear regression method and then, the constants 'C' and 'n' can be obtained from the above equations. The different thermal physical properties of humid air, such as specific heat (C_v), thermal conductivity (K_v), density (ρ_v), viscosity (μ_v), and partial vapor pressure, $P(T)$ were determined by using the expressions given elsewhere (Kumar *et al*., 2012; Tiwari 1997). The experimental errors were evaluated in terms of percent uncertainty (internal + external) for the mass of sugarcane juice evaporated (Kumar *et al*., 2011; Nakra and Chaudhary 1985).

RESULTS AND DISCUSSION

The experimental data recorded for internal heating of sugarcane juice in an aluminum pot during sensible heating mode are given in Tables 1- 5. The data given in Tables 1-5 were used to determine the values of constants 'C' and 'n' in the Nusselt number expression. After evaluating the values of constants, the values of convective heat transfer coefficients were determined from Eq. (1). The results for the constants and the convective heat transfer coefficients are given in Table 6. It can be seen from Table 6 that the values of convective heat transfer coefficients increase with the increase in the rate of heat inputs. These results are also shown in Fig. 2 from which it can be seen that the convective heat transfer coefficients increase with the increase in heat inputs as well as the operating temperature. These results are in accordance with those reported in the literature (Tiwari *et al*., 2003; Kumar *et al*., 2011). The average values of convective heat transfer coefficients for internal heating of sugarcane juice were also calculated and are compared with the results reported for external heating of the sugarcane juice in an aluminum pot by Kumar *et al*., 2011. These results are illustrated in Fig. 3 from which it can be seen that the convective heat transfer coefficients during internal heating of sugarcane juice are higher than in the case of external heating and were found 10.76% higher for the given range of heat inputs. The percent uncertainty (internal + external) was found to be in the range of 39.77 -52.55% and the different values of 'C', 'n' and 'h_c' were found to be within this range.

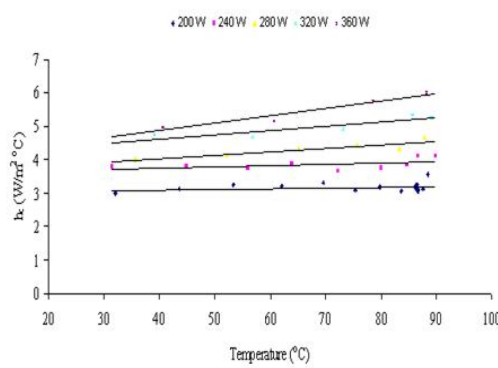

Fig. 2: Variation in h_c Vs Temperature at different heat inputs

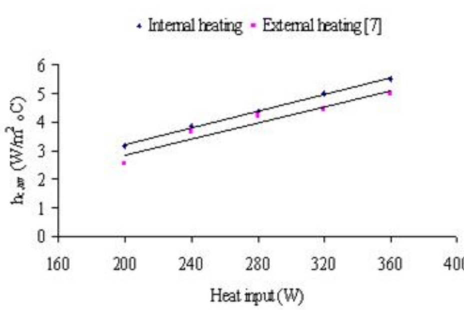

Fig. 3. Comparison of internal and external of sugarcane juice

Table 1: Observations at heat input = 200 W

Time interval (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	γ (%)	m_{evp} (g)
-	19.9	19.4	19.5	67.0	-
10	33.0	32.1	19.9	67.5	0.1
10	44.7	43.6	22.0	82.0	1.9
10	54.7	53.4	21.5	71.0	4.4
10	63.4	62.1	22.3	60.0	8.0
10	71.1	69.6	23.2	88.5	11.5
10	76.4	75.3	24.7	62.0	11.0
10	81.1	79.8	26.1	87.9	19.3
10	84.7	83.6	29.3	89.5	21.3
10	87.4	86.1	23.3	83.4	23.3
10	87.7	86.6	25.7	90.1	31.0
10	87.8	86.7	26.2	88.6	35.5
10	87.8	86.7	22.7	61.0	34.1
10	87.9	86.5	25.5	84.3	36.8
10	87.8	86.6	26.9	87.8	30.2
10	87.6	86.3	27.6	91.5	33.3
10	88.8	87.6	26.5	91.2	33.5
10	90.6	88.5	30.2	93.8	35.2

Table 2: Observations at heat input = 240 W

Time interval (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	γ (%)	m_{evp} (g)
-	16.8	16.6	18.8	64.3	-
10	34.3	31.5	19.0	70.3	0.8
10	47.8	44.9	19.6	82.7	3.1
10	58.8	56.0	22.4	81.7	8.7
10	67.1	63.9	22.3	86.5	10.1
10	74.7	72.2	22.8	86.5	14.9
10	82.8	80.0	24.5	87.4	20.6
10	87.9	84.7	23.5	76.4	25.7
10	91.0	86.7	23.6	89.6	30.7
10	94.1	89.8	23.8	90.2	39.4

Table 3: Observations at heat input = 280 W

Time interval (min)	T_1 (°C)	T_2 (°C)	T_6 (°C)	γ (%)	m_{evp} (g)
-	18.3	18.1	17.4	67.2	-
10	37.8	35.7	19.6	72.4	1.7
10	55.4	52.2	21.0	85.5	7.4
10	68.1	65.1	22.8	90.6	15.3
10	79.1	75.7	24.2	91.1	18.8
10	86.4	83.3	25.4	91.4	21.8
10	92.1	87.8	26.3	92.5	31.6

Table 4: Observations at heat input = 320 W

Time interval (min)	T_1 (°C)	T_2 (°C)	T_6 (°C)	γ (%)	m_{evp} (g)
-	19.5	19.5	18.7	66.8	-
10	43.2	39.2	19.5	83.1	2.1
10	60.8	56.8	22.1	90.6	8.8
10	78.1	73.2	23.8	91.4	28.6
10	92.9	85.7	24.9	92.3	32.1
10	96.0	89.2	27.8	94.1	38.3

Table 5: Observations at heat input = 360 W

Time interval (min)	T_1 (°C)	T_2 (°C)	T_6 (°C)	γ (%)	m_{evp} (g)
-	17.4	17.3	18.4	67.3	-
10	43.4	40.6	19.6	81.0	2.8
10	64.2	60.8	21.8	90.7	13.9
10	84.0	78.5	23.6	91.0	28.6
10	94.8	88.2	29.7	94.1	50.4

Table 6: Values of 'C', 'n' and 'h_c' for internal heating of sugarcane juice

Heat input (W)	Weight (g)	C	n	h_c (W/m^2 °C)
Sugarcane juice				
200	2200	1.03	0.23	2.98-3.56
240	2200	1.01	0.23	3.66-4.12
280	2200	0.99	0.24	4.02-4.67
320	2200	1.00	0.24	4.69-5.35
360	2200	0.99	0.25	4.97-6.00

Conclusions

The convective heat transfer coefficients values increase with an increase in the rate of heat inputs as well as the operating temperature. Its values were observed to vary from 2.98 to 6.00 W/m^2 °C for the heat inputs varying from 200 to 360 W. The convective heat transfer coefficients for internal heating were observed 10.76% higher in comparison to external heating for the mentioned range of heat inputs. This information will be useful in designing better evaporator for jaggery making. The experimental errors in terms of percent uncertainty were found to be in the range of 39.77 - 52.55%.

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