Thermal Performance of Copper and Brass Immersion Rods for the Evaporation of Sugarcane Juice

Mahesh Kumar*[1], Amit Kumar[2] and Nahid Akhtar[3]

ABSTRACT

In this article, thermal performance of copper and brass immersion rods fitted inside aluminum pots has been compared on the basis of the values of convective heat transfer coefficients evaluated during evaporation of sugarcane juice for jaggery production. Experiments were conducted under varying heat input conditions for the sugarcane juice heating of constant mass by copper and brass immersion rods. The experimental data were analyzed by the Nusselt number expression using linear regression method. The convective heat transfer coefficients were observed higher in the case of sugarcane juice heating by copper immersion rod.

Key words: *Sugarcane juice; Evaporation; Natural convective heating; Convective heat transfer coefficient; Jaggery production*

1. INTRODUCTION

Jaggery is the concentrated form of sugarcane juice. It is prepared by the heating and boiling of sugarcane juice in a metallic pot under open conditions. Jaggery is the nutritious sweeteners which is easily and cheaply available in India. In addition to its sweetening characteristics it has several medicinal properties. In India, about 50% of the total sugarcane juice produced is used for manufacture of jaggery.

Thermal models were developed for determining evaporation rate in heat and mass transfer phenomenon for indoor as well as outdoor conditions [1, 2]. Tiwari et al. [3] studied the effect of varying voltage and mass on heat and mass transfer of sugarcane juice during natural convection heating in an aluminum pot. Kumar et al. [4] reported the performance of stainless steel and aluminum pots during sensible mode for external heating arrangement of sugarcane juice for constant mass by varying heat inputs from 200 watts to 360 watts. Recently, the concept of internal heating of sugarcane juice has been employed for the sensible heating of sugarcane juice by aluminum and stainless steel immersion rods [5, 6]. The convective heat transfer coefficients in the case of sensible heating of sugarcane juice by stainless steel immersion rod were found to increase from 2.81 W/m^2 ^{o}C to 5.09 W/m^2 ^{o}C with the increase in heat inputs from 200 watts to 360 watts, whereas in the case of aluminum immersion rod, it were observed to increase from 2.98 W/m^2 ^{o}C to 6.00 W/m^2 ^{o}C for the given range of heat inputs.

In the present research work the comparative heating performance of copper and brass immersion rods during natural convection heating phase of sugarcane juice has been presented. Experiments have

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been conducted for constant mass of the sugarcane juice by varying heat inputs from 240 watts to 360 watts. The temperature ranges for natural convective heating of sugarcane juice is considered up to 90 °C [3-6]. The present research work may be useful in the design of improved sugarcane juice heating pot for jaggery manufacture.

2. EXPERIMENTAL AND THEORETICAL DETAILS

2.1 Experimental set-up and instrumentation

The schematic view of the experimental unit is shown in Fig. 1. It consists of an aluminum pot fitted with a spiral shaped copper or brass immersion rod. The immersion rod is connected through a variac to control the rate of heating of the sugarcane juice. The immersion rod surface temperature T_1 and sugarcane juice temperature T_2 were measured by a digital temperature indicator with calibrated Pt-100 sensors having least count of 0.1 °C. The relative humidity (γ or RH) and temperature above the juice surface T_3 were measured by a digital humidity/temperature meter with a least count of 0.1% RH and 0.1 °C. The heat input was measured by a digital wattmeter having a least count of 1 watt. The mass of juice evaporated during its heating was measured by an electronic weighing balance with a least count of 0.1 g.

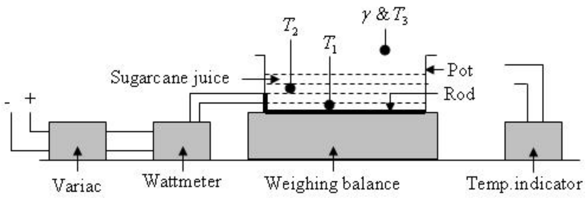

Fig.1. Schematic view of experimental unit

2.2. Experimental procedure

Sugarcane juice sample purchased from the local market was heated in an aluminum pot (200 mm in diameter, 102 mm deep and 1.6 mm thick) fitted with spiral shaped copper immersion rod for different heat inputs ranging from 240 watts to 360 watts. The data of temperatures, mass evaporated, and relative humidity were recorded up to 90 °C (i.e., natural convective heating range) after every 10 minute time interval. Different sets of heating of sugarcane juice were obtained by varying the input power supply which are given in Tables A1 to A4 (Appendix-A). A constant mass of sugarcane juice of 2200 g was taken for each experiment. The mass evaporated during natural convection heating of sugarcane juice was obtained by subtracting two consecutive readings in a given time interval. In order to make a comparison, the above mentioned experimental procedure was followed for sugarcane juice heating in an aluminum pot fitted with brass immersion rod under the same working conditions. The experimental data for sugarcane juice heating under natural convection mode by brass immersion rod are also reported in Tables A1 to A4 in brackets (Appendix-A).

2.3 *Thermal modeling*

The heat transfer coefficient for natural convective heating of sugarcane juice was determined by using the following relations [7]:

$$h_c = (K_v / X)C\,(GrPr)^n \quad (1)$$

The rate of heat utilized to evaporate moisture is given as

$$Q_e = 0.016h_c\,[P(T_c) - \gamma P(T_e)],\ (T_c = T_2,\ \&\ T_e = T_3), \quad (2)$$

From Eq. (1) and (2),

$$Q_e = 0.016\,(K_v / X)C\,(GrPr)^n\,[P(T_c) - \gamma P(T_e)] \quad (3)$$

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

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$$m_{ev} = 0.016 (K_v/X\lambda)C(GrPr)^n [P(T_c) - \gamma P(T_e)A_p t] \quad (4)$$

Let $0.016 (K_v/X\lambda) [P(T_c) - \gamma P(T_e)]A_p t = K$

$$\therefore (m_{ev}/K) = C(Gr\,Pr)^n \quad (5)$$

$$\ln(m_{ev}/K) = \ln C + n \ln(Gr\,Pr) \quad (6)$$

Values of n and C in Eq. (6) are obtained by using the simple linear regression method. The different thermal physical properties of humid air were determined by using the expressions given elsewhere [7].

3. RESULTS AND DISCUSSION

The experimental data recorded during the natural convective heating of sugarcane juice by copper and brass immersion rods fitted in aluminum pots are given in Tables A1 to A4. The data for brass rod are given in brackets. These data were used to determine the values of constants (C & n) in the Nusselt number expression and then the values of convective heat transfer coefficients were determined from Eq. (1). The results for the experimental constants and the convective heat transfer coefficients during natural convective heating of sugarcane juice for different rate of heat inputs by copper immersion rod are given in Table 1. The corresponding evaluated values of the experimental constants and the convective heat transfer coefficients for heating of sugarcane juice by brass immersion rod are also given Table 1 in brackets.

Table 1: Values of *C, n, hc, and* $h_{c,av}$ for sugarcane juice heating by copper (brass) immersion rods at different heat inputs

Heat input (W)	C	n	h_c (W/m^2 °C)	$h_{c,av}$ (W/m^2 °C)
240	1.02 (0.99)	0.23 (0.22)	3.47-4.35 (3.25-3.67)	3.82 (3.40)
280	1.01 (1.00)	0.24 (0.23)	4.06-4.97 (3.79-4.45)	4.44 (4.13)
320	1.00 (0.99)	0.24 (0.24)	4.76-5.42 (4.06-5.04)	5.01 (4.53)
360	0.99 (0.99)	0.25 (0.24)	5.09-6.15 (4.56-5.17)	5.53 (4.84)

It can be seen from Table 1 that the values of convective heat transfer coefficients during natural convective heating of sugarcane juice by copper and brass immersion rods increase with the increase in the rate of heat inputs. The effect of rate of heat inputs on the convective heat transfer coefficients for the heating of sugarcane juice in aluminum pots fitted with copper and brass immersion rods are illustrated in Figures 2 to 5. It can be seen from these Figures that the convective heat transfer coefficients increase with the increase in heat inputs. It can also be seen that the convective heat transfer coefficients increase with the increase in operating temperature for the given range of heat inputs. The trend of the results is observed in accordance with those reported in the literature [3-6]. It is also observed that the convective heat transfer coefficients during heating of sugarcane juice by copper immersion rod are higher than in the case of brass rod for each rate of heat inputs.

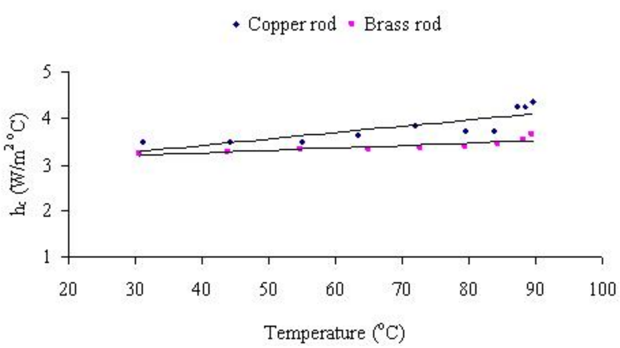

Fig .2. Variation in h_c vs. Temperature at 240 watts

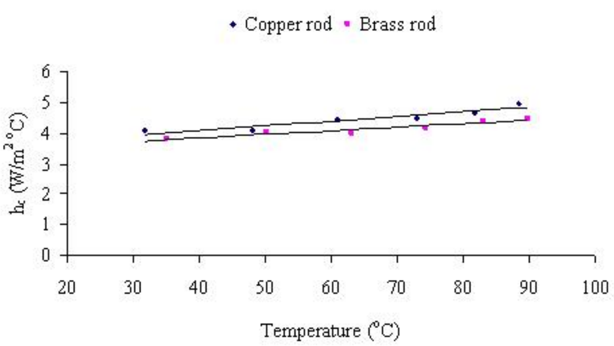

Fig .3. Variation in h_c vs. Temperature at 280 watts

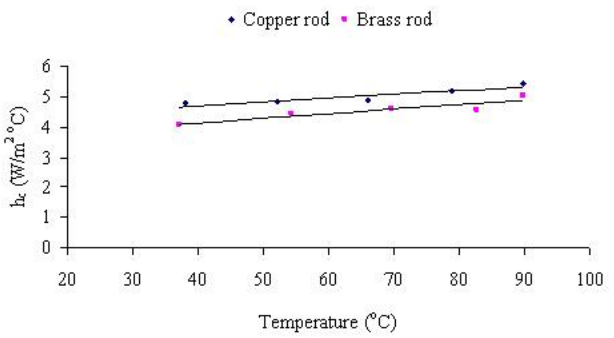

Fig .4. Variation in h_c vs. Temperature at 320 watts

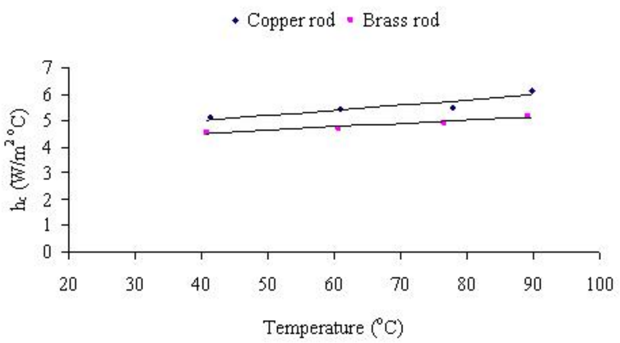

Fig .5. Variation in h_c vs. Temperature at 320 watts

In order to make a comparison the average values of convective heat transfer coefficients for the heating of sugarcane juice by copper and brass immersion rods were also calculated and are illustrated in Figure 6. It can be seen from this Figure that the convective heat transfer coefficients during heating of sugarcane juice in an aluminum pot by copper immersion rod are higher than in the case of brass immersion rod. The average value of the convective heat transfer coefficients during heating of sugarcane juice by copper immersion rod were observed 11.12% higher than in the case of brass rod for the mentioned range of heat inputs.

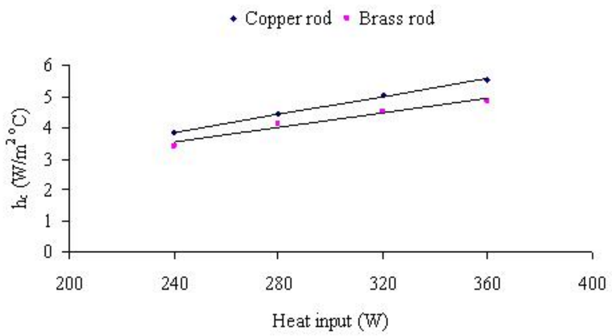

Fig .6. Comparison of h_c of sugarcane juice by copper and brass rods

4. CONCLUSIONS

The values of convective heat transfer coefficients for sugarcane juice heating by copper and brass immersion rods fitted in aluminum pots were observed to increase from 3.47 to 6.15 W/m^2 °C and from 3.25 to 5.17 W/m^2 °C respectively with an increase in rate of heat inputs from 240 watts to 360 watts. The convective heat transfer coefficients were also observed to increase with an increase in operating temperature for the given range of heat inputs. The average values of convective heat transfer coefficients during natural convective heating of sugarcane juice by copper immersion rod are observed 11.12% higher than in the case of brass immersion rod. This research work may be useful in the design of improved sugarcane juice heating equipment for jaggery making.

Nomenclature

A_p	Area of pan, m^2
C	Experimental constant
C_v	Specific heat of humid air, J/kg °C
g	Acceleration due to gravity, m/s^2
Gr	Grash of number $=\beta\, g\, X^3 \rho_v^{\,2} \Delta T/ \mu_v^{\,2}$
h_c	Convective heat transfer coefficient, W/m^2 °C
$h_{c,av}$	Average convective heat transfer coefficient, W/m^2 °C
K_v	Thermal conductivity of humid air, W/m °C
m_{ev}	Mass evaporated, kg
n	Experimental constant

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Nu	Nusselt number = $h_c X / K_v$
Pr	Prandtl number=$\mu_v C_v / K_v$
$P(T)$	Partial vapor pressure at temperature T, N/m^2
Q_e	Rate of heat utilized to evaporate moisture, J/m^2 s
t	Time, s
ΔT	Effective temperature difference, ^{o}C
W	Heat input, watts
X	Characteristic dimension, m
β	Coefficient of volumetric expansion (K^{-1})
γ	Relative humidity (%)
λ	Latent heat of vaporization, J/kg
μ_v	Dynamic viscosity of humid air, N s/m^2
ρ_v	Density of humid air, kg/m^3

APPENDIX

Table A1: Observations for sugarcane juice heating by copper (brass) rods at 240 W

Time interval (min)	T_1 (^{o}C)	T_2 (^{o}C)	T_3 (^{o}C)	γ (%)	m_{ev} (g)
10	33.0 (33.5)	31.2 (30.6)	17.8 (19.3)	49.4 (72.2)	1.3 (0.9)
10	46.1 (46.9)	44.2 (43.8)	18.9 (19.9)	59.7 (73.0)	6.9 (5.9)
10	56.9 (58.3)	55.0 (54.9)	19.4 (20.9)	62.7 (84.5)	7.7 (6.8)
10	65.7 (68.3)	63.4 (64.9)	20.7 (21.7)	63.6 (88.5)	9.0 (8.6)
10	74.9 (76.4)	72.0 (72.8)	21.2 (22.0)	64.3 (92.3)	12.0 (10.8)
10	82.0 (83.1)	79.4 (79.4)	22.3 (22.4)	67.2 (86.6)	17.6 (16.7)
10	86.3 (88.5)	83.7 (84.4)	23.5 (24.6)	74.8 (94.3)	25.0 (18.7)
10	91.7 (92.7)	87.1 (88.2)	22.2 (25.1)	73.5 (94.6)	26.6 (25.6)
10	93.1 (94.8)	88.4 (89.4)	22.9 (27.5)	80.8 (94.9)	33.8 (40.6)

Table A2: Observations for sugarcane juice heating by copper (brass) rods at 280 W

Time interval (min)	T_1 (^{o}C)	T_2 (^{o}C)	T_3 (^{o}C)	γ (%)	m_{ev} (g)
10	33.9 (37.9)	31.9 (35.0)	16.9 (20.4)	72.4 (76.4)	1.6 (1.6)
10	50.2 (53.9)	48.1 (50.1)	17.8 (20.6)	85.5 (72.7)	6.4 (8.0)
10	64.0 (67.0)	61.0 (63.2)	19.2 (21.4)	90.6 (78.9)	14.4 (10.9)
10	76.1 (79.1)	72.9 (74.4)	19.6 (21.9)	91.1 (81.1)	16.4 (18.1)
10	85.4 (89.0)	81.6 (83.2)	21.1 (24.6)	91.4 (85.9)	22.4 (20.1)
10	93.5 (96.2)	88.4 (89.9)	21.6 (23.1)	92.5 (86.7)	28.9 (28.5)

Table A3: Observations for sugarcane juice heating by copper (brass) rods at 320 W

Time interval (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	γ (%)	m_{ev} (g)
10	42.2 (39.2)	38.1 (37.0)	19.5 (19.5)	44.5 (47.9)	2.3 (1.9)
10	56.5 (57.6)	52.1 (54.4)	22.1 (20.8)	47.5 (74.5)	8.5 (8.5)
10	70.9 (73.5)	66.1 (69.6)	23.8 (21.5)	58.0 (81.0)	16.8 (18.7)
10	85.0 (86.5)	78.9 (82.7)	24.9 (22.5)	92.9 (81.4)	29.4 (30.8)
10	97.5 (95.7)	89.8 (89.8)	27.8 (23.1)	91.3 (87.4)	37.7 (35.4)

Table A4: Observations for sugarcane juice heating by copper (brass) rods at 360 W

Time interval (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	γ (%)	m_{ev} (g)
10	44.4 (44.3)	41.3 (40.7)	18.9 (22.8)	65.3 (56.2)	2.9 (2.6)
10	65.0 (65.1)	60.9 (60.8)	19.2 (23.0)	63.1 (79.4)	15.9 (12.9)
10	82.2 (81.8)	77.8 (76.5)	21.1 (24.0)	91.1 (87.9)	26.6 (25.6)
10	97.1 (95.9)	89.9 (89.3)	22.1 (28.1)	92.7 (93.7)	51.2 (45.1)

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