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# Evaluation and prediction of overall heat transfer coefficient of Scraped surface heat exchanger during *kheer* making

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**Abstract**
Scraped surface heat exchanger (SSHE) is one of the adaptable equipments for products which are viscous, containing suspended constituents which tend to deposit and form layer on the heat transfer surface. The study was undertaken to evaluate and predict the overall heat transfer coefficient (U) of SSHE for making *kheer*. The performance of the developed SSHE was evaluated at three different steam pressures (1.0, 1.5 and 2.0 kg/cm$^2$), scraper speeds (10, 20 and 30 rpm) and batch sizes (10, 15 and 20 kg) during *kheer* making. There was significant increase in the U-value with increase in operating steam pressures, batch sizes and scraper speeds. The quality of the *kheer* prepared in SSHE at optimized condition (i.e. 1 kg/cm$^2$ steam pressure, 20 kg batch size and 30 rpm scraper speed) was found superior in terms of the sensory attributes, having U-value of 1197.40 W/m$^2$K, steam side heat transfer coefficient ($h_o$) was 8634.60 W/m$^2$K and product side heat transfer coefficient ($h_i$) was 2251.53 W/m$^2$K. The regression equation was developed for predicting the U-value.

**Keywords:** *Kheer*, scraped surface heat exchanger, overall heat transfer coefficient

## 1. Introduction

India is one of the most economic and largest milk producers in the world; produced around 187.7 million tonnes of milk in the year 2018-19 (www.nddb.coop) [1]. According to the report of Ministry of Agriculture and Farmers' Welfare (2018) [2], about 48% of the total milk produced is either consumed at the producer level or sold to non-producers in the rural areas. The balance 52%, about 40% of it is handled by organised sector and remaining 60% by unorganised sector. Due to this, the major stress is being laid on the manufacture of indigenous dairy products. The foremost concerns for manufacturing of traditional Indian dairy products at unorganised sector are mechanisation of process, cost-effectiveness of technologies, productivity and uniformity of product throughout the year with quality control measures.

*Kheer* is a traditional milk product in South-east Asia and is identified by different names in different part of the country, such as '*Kheer'* in north western region, 'Payasam' in southern region, 'Payas' in eastern region, 'Phirni' in northern region and 'Kheech' in Mewar region of Rajasthan. *Kheer* is partially heat-desiccated cereal-based product. It has a semi-solid consistency due to partially disintegrated cooked rice grains dispersed in viscous liquid (Jha *et al*., 2002) [3]. It is considered to be a nutritious food for people of all ages and is characterized by sweet, nutty and pleasant flavour that is highly acceptable (Aneja *et al*., 2002; Jha *et al*., 2002) [4, 3]. Christie and Shah, (1992) [5]; Dodeja *et al*., (1992) [6] reported that scraped surface heat exchangers find extensive use in thermal processing of liquid foods that have suspended solids, high thickness which are temperature dependent or having Non-Newtonian rheology. Several studies were carried out for making different traditional Indian dairy products using SSHE. Abhichandani *et al.* (1995) [7] have correlated physical properties of different fluids with the heat transfer and developed empirical relations for calculating scraped film heat transfer coefficient (Nu) and U-value for ghee making. Cuevas and Cheryan (1982) [8] have reported that U-values achieved depend on blade rotational speed and mass flow rate. Patel (2003) [9] reported the U-value of *sandesh* making machine ranging from 131.08 to 639.87 W/m$^2$ K under different operating conditions. Dhotre (2006) [10] reported significant increase in U-values with increase in the scraper speed. Bhadania (1998) [11]; Dodeja *et al*., (1990) [12] had reported in their studies that with increase in rotor speed, the overall heat transfer co-efficient also increases as long as the viscosity of the product are not predominant. Dodeja *et al*., (1989) [13] discussed about the film co-efficient in thin film SSHE depends on mass flow rate, rotor speed and number of blades. Abichandani and Sarma (1988) [14] had developed the relation between film co-efficient, mass flow rate and rotor speed. Dhotre (2006) [10] reported values of $h_o$ and $h_i$, which increased with increase in scraper speeds and thermization temperatures but decreased with increase in moisture content of chakka. Patel (2006) [15] reported $h_i$ and $h_o$ values obtained by using Wilson-Plot technique for continuous basundi making machine. The mechanization of *kheer* was reported by Chauhan *et al.,* (2018) [16].

Earlier some researcher had reported literature on heat transfer behaviour of SSHE for making different indigenous products, however past studies doesn't provide any evidence on heat transfer evaluation of SSHE for *kheer* making. Therefore, this study was aimed, to evaluate the performance of SSHE for *kheer* making. The design optimization for any developed machine, the heat transfer analysis is one of the most important decisive factor; for this purpose the overall heat transfer coefficient along with steam side and product side heat transfer coefficient were determined.

## 2. Materials and Methods

The study was carried out at the Dairy Engineering lab of the Sheth Mansukhlal Chaganlal College of Dairy Science, Anand Agricultural University, Anand. The standardised pasteurized milk (4.5% fat and 8.5% SNF) procured from Amul was used for preparation of kheer. A local variety of rice *(Oryza sativa*), Gujarat 17, was used, a fine crystalline sugar and other additives like saffron and cardamom were used for *kheer* preparation and were procured from the local market. The method for preparing *kheer* reported by Chauhan *et al*., (2018) [16] was adopted in this study.

### 2.1 Product preparation

*Kheer* was prepared in multipurpose SSHE having 600 mm length of product tube, whose bore size was 500 mm; with 3 mm wall thickness confirming to prescribe surface finish and made of AISI-304 grade stainless steel. The product tube has been provided with a jacket which covers 550 mm length of SSHE leaving 25 mm length unjacketed on either side with an angle of 180º at the lower part of the product tube. The four-spring loaded Teflon edged scraper blades were used, and driven by Variable frequency drive operated electric motor, three phase AC motor of 0.75 hp was used to drive the assembly (Chauhan *et al.,* 2018) [16]. The experimental trials were carried out at different operating parameters that are scarper speeds ($S_1$=10 rpm., $S_2$=20 rpm., $S_3$=30 rpm.), operating steam pressures ($P_1$=1.0 kg/cm$^2$, $P_2$=1.5 kg/cm$^2$, $P_3$=2.0 kg/cm$^2$) and batch sizes ($B_1$=10 kg, $B_2$=15 kg, $B_3$=20 kg). The control sample of kheer was prepared in the lab by conventional method. The sensory attribute of product prepared in the machine was evaluated with a 9-point hedonic score by a panel of 8 judges.

Hand operated needle valve was installed in steam pipe line; Bourdon tube pressure gauge for the steam pressure in the jacket; Resistance temperature detector (RTD) for milk temperature; the quantity of condensate coming out from the steam trap of the jacket was measured to estimate the steam consumption of the SSHE.

### 2.2 Chemical analysis

The standardized milk was used for *kheer* making, was analysed for fat (BIS IS:1224-1 1977) [17], total solid (TS %) as per the methods given in "Ist Handbook of Food Analysis Part XI Dairy Products. The fat (%) of *kheer* sample {(BIS IS:1224-1 1977) [17] for sweetened condensed milk};protein (Kjeldahl method), moisture (IS:1479-2 1961) [18], ash (burning in muffle furnace) and total carbohydrate were calculated after determining the percentage of moisture, protein, fat and ash. The composition of *kheer* was analysed to estimate specific heat of *kheer*.

### 2.3 Heat transfer Evaluation

#### 2.3.1 Determination of overall heat transfer co-efficient

The heat transfer from steam to the product is used for increasing temperature of the product up to the desired value and for the evaporation of moisture. The rate of evaporation was recorded to calculate the overall heat transfer coefficient. Therefore, the total heat transfer (Q), is determined by the equation:

$$Q = M \times C_p \times (T_p - T_i) + (E \times L) \quad (1)$$

Where, M = Mass of mixture, kg
$C_{pm}$ = Specific heat of mixture, kJ/kg K
$T_p$ = Evaporation temperature, K
$T_i$ = Temperature of feed mixture, K
E = rate of evaporation, kg/h
L = latent heat of evaporation, kJ/kg

Now, using Fourier's heat flow equation,

$$M \times C_p \times (T_p - T_i) + (E \times L) = U \times A \times (T_s - T_p) \quad (2)$$

**Where**
U = Overall heat transfer co-efficient, W/m$^2$ K
A = Effective heat transfer area of the SSHE, m$^2$
$T_s$ = Temperature of steam corresponding to steam pressure, K
$T_p$ = Temperature of the product, K

#### 2.3.2 Determination of steam side film heat transfer coefficient

The $h_o$ of SSHE was calculated assuming film type condensation of steam using the equation based on the Nusselt theory (Kreith and Bohn, 1986) [19].

$$h_o = 0.725 \times \left[ \frac{\rho_c(\rho_c - \rho_v) H'_L \, g \, Kc^3}{D \times \mu_c (T_s - T_{wc})} \right]^{0.25} \quad (4)$$

**Where**
$\rho_c$ = Density of condensate, kg/cm$^3$
$\rho_v$ = Density of vapour, kg/cm$^3$
$H_L$ = Latent heat of condensation, J/kg
$H'_L = H_L + 3/8\,Cpc\,(T_s - T_{wc})$
g = Acceleration of gravity, m/s$^2$
Kc = Thermal conductivity of condensate film, W/mK
D = Diameter of SSHE, m
$\mu_c$ = Viscosity of condensate, N.S/m$^2$
$T_s$ = Steam condensation temperature at prevailing pressure, K
$T_{wc}$ = Wall surface temperature, K

$C_{pc}$ = Specific heat of condensate J/kgK

The physical properties of condensate required were obtained from properties table (Kreith and Bohn, 1986) [19] at the mean film temperature $T_f$. The mean film temperature of the condensate was calculated by the relationship given below (McCabe and Smith, 1976) [20].

$$T_f = T_s - 0.75\,(T_s - T_{wc}) \quad (5)$$

For calculating $h_o$, the wall temperature ($T_{wc}$) must be known. The method consists of first assuming a wall temperature (steam side), then calculating $T_f$ using equation (5). Then $h_o$ was calculated by using equation (4) and the physical properties of condensate at $T_f$. The heat flux equivalent concept was then used to calculate a "new" wall temperature. The overall temperature drop is proportional to 1/U, and the temperature drop through a given resistance is proportional to that resistance.

$$\frac{\Delta T}{1/U} = \frac{T_s - T_{wc}}{1/h_o} \quad (6)$$

Therefore, the wall temperature on the steam side ($T_{wc}$) is:

$$T_{wc} = T_s - \Delta T \times U/h_o \quad (7)$$

This new wall temperature was then used to repeat the above set of calculations, and this procedure is repeated until the two values (i.e. the assumed wall temperature and the "new" calculated wall temperature) converge. The calculation of $h_o$ as above, requires several interactions to converge. Therefore, graphical methods were used in this study adopting the same concept. In this method a graphical relationship between ($T_s$ - $T_{wc}$) and calculated values of $h_o$ using equation (4) were developed by assuming different values of temperature drop ($T_s$ - $T_{wc}$) through the condensate film. $T_s$ was taken corresponding to the operating steam pressure of SSHE. The calculated $h_o$ values from equation (6) were graphically presented corresponding to different values of ($T_s$ - $T_{wc}$) in the graphical relationship obtained between ($T_s$ - $T_{wc}$) and $h_o$ obtained from Nusselt equation (4). The point at which these two curves intersect is the operating $h_o$ of the SSHE.

#### 2.3.3. Determination of product side film heat transfer coefficient

The heat transfer resistance created by the film resistance on the product side of the heat transfer surface is very complex (Heldman, 1981) [21]. The product side film heat transfer coefficient ($h_i$) is the index of heat uptake by the product from the wall. The overall heat transfer is mainly governed by the value of $h_i$ being the least value.

The equation for determining the U-value is as under.

$$U = \frac{1}{\frac{r_m}{r_e} \times \frac{1}{h_o} + \frac{r_e - r_i}{K} + \frac{r_m}{r_i} \times \frac{1}{h_i}} \quad (8)$$

The SSHE designed for the manufacture of *kheer* in the study, the ratio of $r_m/r_e$ and $r_m/r_i$ approach unity.

$$\frac{1}{U} = \frac{1}{h_o} + \frac{b}{K} + \frac{1}{h_i} \quad (9)$$

Where, b is the thickness of the heat transfer wall. The value of b/K was obtained from the thermal conductivity (16.2 W/mK) and thickness (0.005 m) of the wall. The product side film heat transfer co-efficient was obtained from the following equation,

$$\frac{1}{h_i} = \frac{1}{U} - \frac{1}{h_o} - \frac{b}{K}$$

### 2.4 Statistical Analysis

The data collected were analyzed statistically to know the best combination of the treatments applied. Factorial Completely Randomized Block Design described by Snedecor and Cochran (1994) [22] was adopted to analyze the data. The regression equation was also developed.

## 3. Result and Discussion

The present study was conducted to evaluate the overall heat transfer co-efficient of SSHE for *kheer* making under different operating conditions. The experimental trials were carried out at different scarper speeds (S), operating steam pressures (P) and batch sizes (B). The different combination of process parameters were taken as treatments.

### 3.1 Overall heat transfer coefficient

U-value obtained during thermal processing is function of properties of material being processed, design of machine, speed of scraper assembly, steam pressure etc. The mean values of overall heat transfer coefficient obtained at different levels of operating conditions during manufacturing of *kheer* in the SSHE were shown in table 1. The U-values obtained ranged between 913.62 and 1228.16 $W/m^2K$ at various combinations of operating parameters studied. The p-values from ANOVA were indicated at different steam pressure, batch size and scraper speed on Overall heat transfer coefficient during *kheer* making in table 2.

**Table 1:** Mean values of overall heat transfer coefficient at all levels of operating variables

| Steam pressure | Mean value ($W/m^2K$) | Batch size | Mean value ($W/m^2K$) | Scraper speed | Mean value ($W/m^2K$) |
|---|---|---|---|---|---|
| $P_1$(1.0 $kg/cm^2$) | 1045.42 | $B_1$(10 kg) | 1021.29 | $S_1$(10 rpm) | 980.34 |
| $P_2$(1.5 $kg/cm^2$) | 1062.65 | $B_2$(15 kg) | 1067.32 | $S_2$(20 rpm) | 1047.74 |
| $P_3$(2.0 $kg/cm^2$) | 1087.94 | $B_3$(20 kg) | 1107.40 | $S_3$(30 rpm) | 1167.93 |
| $SE_M$ | 3.06472 | $SE_M$ | 3.06472 | $SE_M$ | 3.06472 |
| C.D. at 5% | 8.89 | C.D. at 5% | 8.89 | C.D. at 5% | 8.89 |

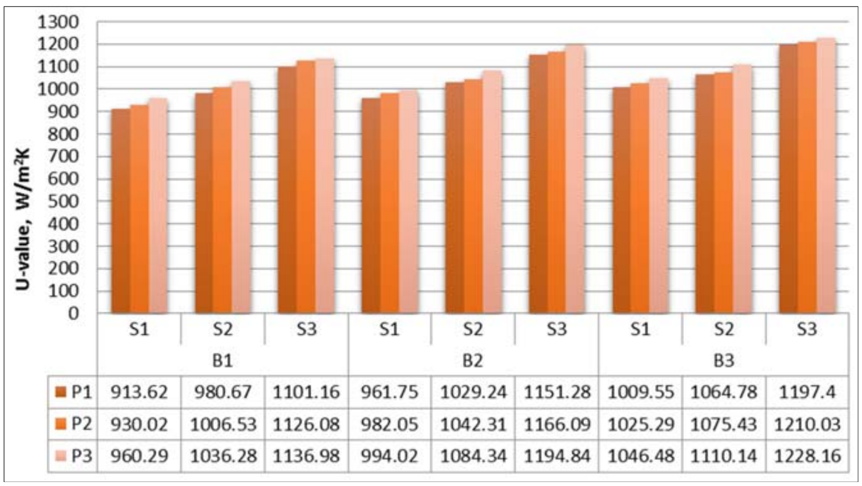
**Table 2:** p-values from ANOVA to indicate significance of steam pressure, batch size and scraper speed individually and interactively on overall heat transfer coefficient

| Source | SEm | C.D. | Result | CV% |
|---|---|---|---|---|
| P | 3.0592 | 8.79 | * | 1.2205% |
| B | 3.0647 | 8.84 | * | |
| S | 3.0436 | 8.81 | * | |
| PxB | 5.3085 | NS | NS | |
| PxS | 5.3132 | NS | NS | |
| BxS | 5.3082 | NS | NS | |
| PxBxS | 9.1941509 | NS | NS | |

* Significant effect ($p<0.05$), NS-Non significant

### 3.1.1. Effect of Steam pressure on U-value

The mean values of the overall heat transfer coefficient obtained at steam pressure $P_1$, $P_2$ and $P_3$ were 1045.42, 1062.65 and 1087.94 $W/m^2K$ respectively, during *kheer* making (table 1). It can be inferred from figure1 that with the increase in steam pressure, there was significant increase ($p<0.05$) in U-values at various levels of scraper speed and batch size during *kheer* making process. The enthalpy of steam increases as the pressure of steam increases, this result in significant increase in U-value. Though the U-value increased significantly with higher steam pressure but the product obtained at higher level of steam pressure resulted in uncooked rice, burning problem, high concentration, which was not acceptable by the judges. Bhadania (1998) [11] reported that U-values increased with increase in steam pressure and scraper speed but decreased predominantly at higher concentration. Therefore, the lower steam pressure resulted in desired rate of evaporation, enabled proper cooking of rice, avoided burning and fouling, in turn lead to acceptable quality of the final product.

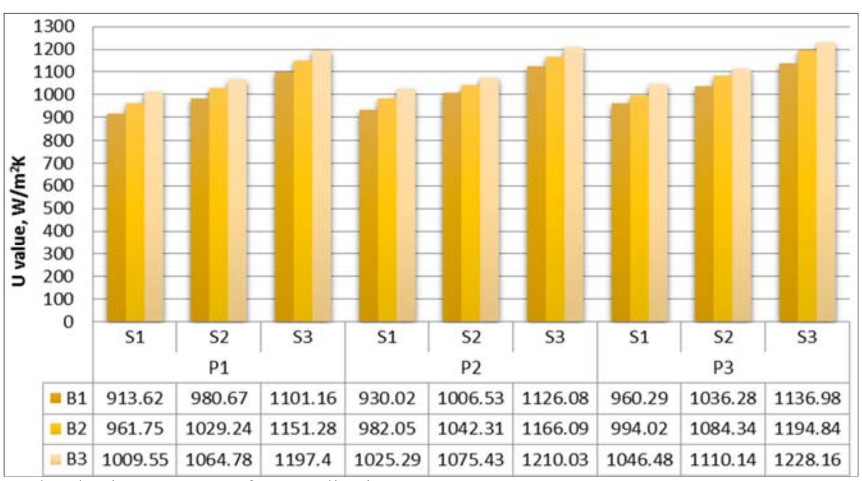



Each value is an average of two replications

**Fig 1:** Effect of steam pressure on overall heat transfer coefficient (U) during *kheer* making

### 3.1.2. Effect of batch size on U-value

The mean values of the overall heat transfer coefficient obtained at different levels of batch size were 1021.29, 1067.32 and 1107.40 $W/m^2K$ at $B_1$, $B_2$ and $B_3$ respectively. It can be inferred from fig.2 that with the increase in the batch size, the U-value increased under all operating conditions studied. The effect of batch size on the U-value was found significant ($p<0.05$). The higher batch size utilized more contact surface area for heat transfer in the heat exchanger resulting into higher rate of evaporation and in turn higher U-values were obtained. At lower batch size, larger surface area was available causing more evaporation of moisture, which lead to over desiccation of product and deposition of denatured protein layer was also observed. The rice grains were also found uncooked.



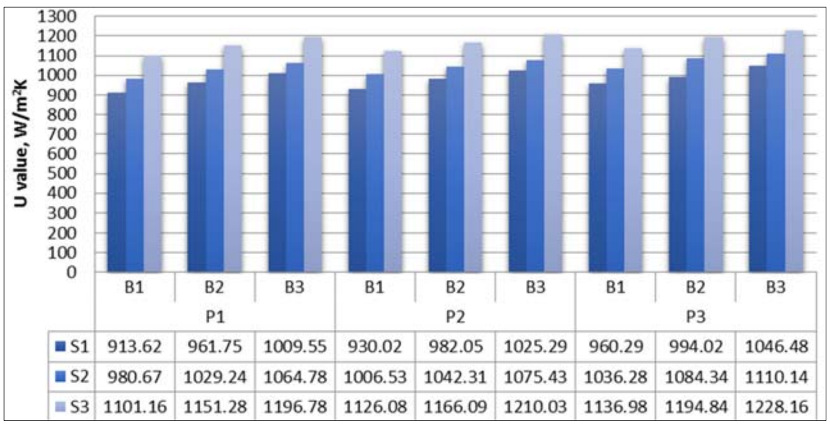

Each value is an average of two replications

**Fig 2:** Effect of batch size on overall heat transfer coefficient (U) during *kheer* making.

### 3.1.3. Effect of scraper speed on U-value

The mean values of the overall heat transfer coefficient were recorded to be 980.34, 1047.74 and 1167.93 W/m$^2$K at $S_1$, $S_2$ and $S_3$ scrapper speeds respectively (table 1) during *kheer* making. It can be inferred from the figure 3 and table 2 that with increase in scraper speed, there was significant increase in the U-values ($p$<0.05). The scraping blades minimized fouling through continuous scrapping cum mixing radially and improved heat transfer rates by the action of mechanically induced turbulence. High heat transfer coefficients were achieved because the boundary layer was continuously replaced by fresh material. Cuevas and Cheryan (1982) [8] reported that U-values achieved depended on rotational speed of blade and mass flow rate. Similar trend of scraper speed on U-value have been reported during manufacture of other indigenous dairy products (Bhadania, *et al.,* 2004; Patel and Bhadania, 2005, Dhotre, 2006; Patel, 2006) [23, 24, 10, 15]. Furthermore, higher U-value was achieved due to increase in product side heat transfer coefficient at increased level of scraper speed. Though the U-values were higher at greater scrapper speed, it lead to breakage of rice grains into fines and resulting into pasty consistency of product, while, at lower scrapper speed, the product residence time increased which contributed to the burning problem. Punjrath *et al.* (1990) [25] reported similar effect at higher rotor speed causing the capacity to increase but the quality of the product deteriorated.

The interaction effect of steam pressure and batch size; steam pressure and scraper speed; batch size and scraper speed and combination of all three had non-significant ($p$<0.05) effect. The $P_3B_3S_3$ combination resulted in highest U-value of 1228.1 W/m$^2$K. However, considering the importance of overall heat transfer coefficient in manufacturing of dairy products and sensory quality of the product, the $P_1B_3S_3$ (1.0 kg/cm$^2$ of steam pressure, 30 kg of batch size and 30 rpm of scrapper blade) combination resulted in U-value of 1196.78 W/m$^2$K and superior sensory quality of *kheer* as judged by experts panel.




Each value is an average of two replications

**Fig 3:** Effect of scraper speed on overall heat transfer coefficient (U) during *kheer* making

### 3.2 Regression equation for prediction of U-values

The regression equations were developed in order to predict the U-values under different set of operating conditions. These equations were useful in optimization of design and operating conditions of the SSHE. The relationship between batch size and U-value at all levels of steam pressures is depicted in fig. 4, 5 and 6 at $S_1$, $S_2$ and $S_3$ rpm respectively. The linear regression trend line equations obtained for $S_1$ condition were y = 8.619x + 870.9 ($R^2$ = 0.984), y = 9.526x + 836.2 ($R^2$ = 0.997) and y = 9.593x + 817.7 ($R^2$ =1) for $P_1$, $P_2$ and $P_3$ conditions respectively (fig. 1). The values of $R^2$ for $P_1$, $P_2$ and $P_3$ conditions were 98.4%, 99.7% and 100%, which indicated that the regression equations obtained were highly fitting the experimental data.

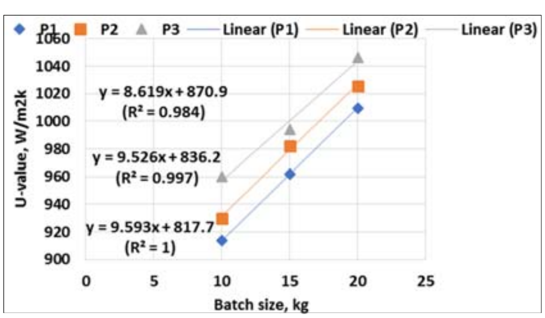



**Fig 4:** Effect of batch size and steam pressure on U-value during *kheer* making at $S_1$

The linear regression trend line equations obtained for $S_2$ condition were y = 7.386x + 966.1 ($R^2$ = 0.970), y = 6.89x + 938.0 ($R^2$ = 0.999) and y = 8.411x + 898.7 ($R^2$ =0.992) for $P_1$, $P_2$ and $P_3$ conditions respectively (fig. 2). The values of $R^2$ for $P_1$, $P_2$ and $P_3$ conditions are 97.0%, 99.9% and 99.2% respectively.

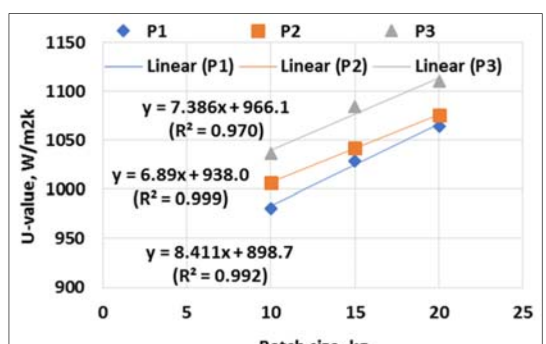



**Fig 5:** Effect of batch size and steam pressure on U-value during *kheer* making at $S_2$

Similarly, the linear regression trend line equations obtained for $S_3$ condition were y = 3.318x + 1164 ($R^2$ = 0.992), y = 4. 356x + 1105 ($R^2$ = 0.967) and y = 3.582x + 1067 ($R^2$ =0.951) for $P_1$, $P_2$ and $P_3$ conditions respectively (fig. 3). The values of $R^2$ for $P_1$, $P_2$ and $P_3$ conditions are 99.2%, 96.7% and 95.1%

respectively. The $R^2$ values obtained at $S_2$ and $S_3$ conditions indicate that the regression equations are closely representing the experimental data obtained under field conditions.

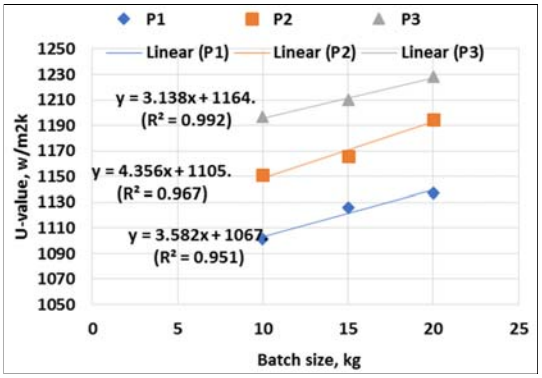



**Fig 6:** Effect of batch size and steam pressure on U-value during *kheer* making at $S_3$

### 3.3 Steam side and Product side films heat transfer coefficient

The product side film heat transfer coefficient ($h_i$) is the index of heat uptake by the product from the wall. The overall heat transfer is mainly governed by the value of $h_i$ being the least value. The value of $h_i$ depends not only on the operating variables of the machine but also on the properties of the material which is under processing. The $h_o$ and $h_i$ values have been calculated for operating conditions which produced the *kheer* having higher sensory acceptability, $P_1B_3S_3$ and $P_1B_2S_3$ conditions as reported by Chauhan *et al*., (2018) [16].

The values of $h_o$ obtained by using Nusselt equation and the experimental $\Delta T$ and U are plotted in the fig.7 and fig.8 for $P_1B_2$ and $P_1B_3$ operating conditions, respectively. The wall temperature of 118.75 °C, 118.5 °C and 118.2 °C at 10rpm, 20rpm and 30 rpm of scraper blade respectively at $P_1B_2$ operating condition. Similarly, the wall temperature was 118.5°C, 118.5°C and 118°C at 10, 20 and 30 rpm of scarper speed respectively for $P_1B_3$ operating conditions.

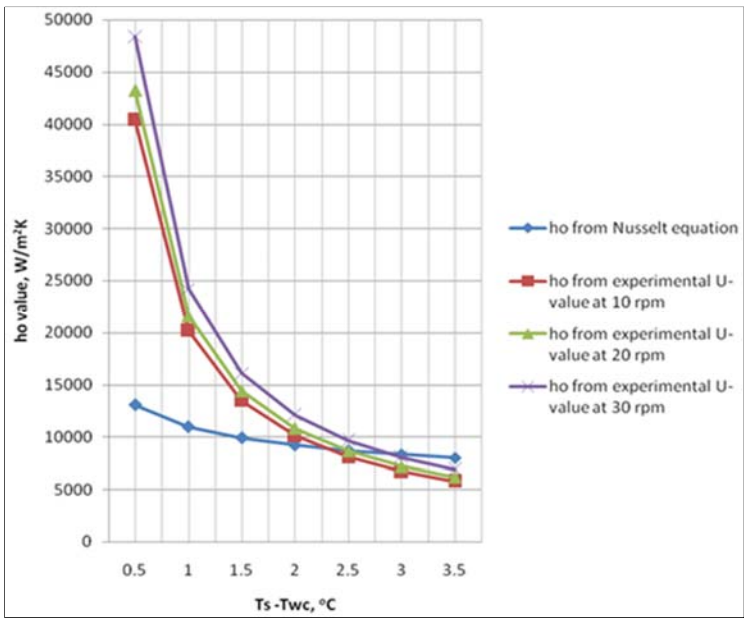



**Fig 7:** Relationship between (Ts-Twc) and the $h_o$ calculated from Nusselt equation and experimental U and △T values in $P_1B_2$ conditions

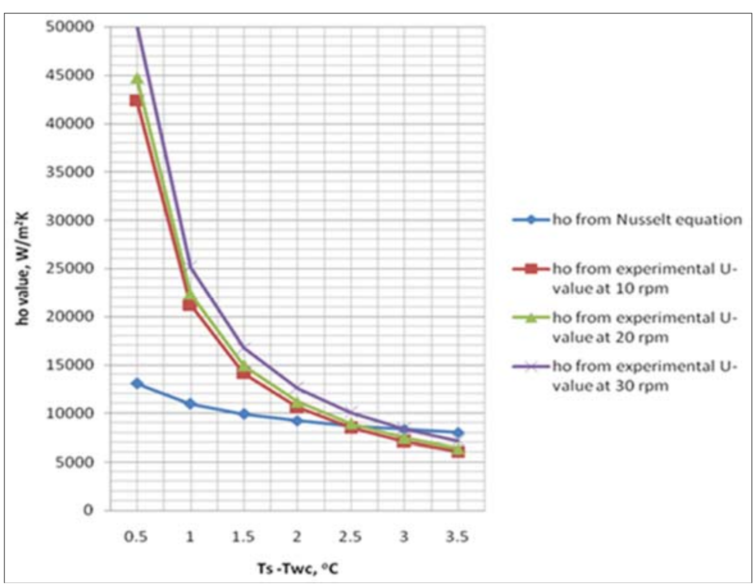



**Fig 8:** Relationship between (Ts-Twc) and the $h_o$ calculated from Nusselt equation and experimental U and △T values in $P_1B_3$ conditions

The $h_o$ and $h_i$ values obtained during manufacturing of *kheer* at $P_1B_2$ and $P_1B_3$ operating conditions are cited in the Table 3. The $h_i$ values were 2251.53 and 2455.82W/m$^2$K at $P_1B_3S_3$ and $P_1B_2S_3$ conditions respectively. The $h_o$ value decreased with increase in batch size, while slight decrease with increase in scraper speed. Bhadania (1998) [11] reported the values of $h_o$ as 10700, 11850 and 14625 W/m$^2$ K in $HE_1$, $HE_2$, and $HE_3$ respectively at 98.1 kPa steam pressure during manufacture of khoa using three stages SSHE. Patel (2006) [15] reported that the values of $h_o$ and $h_i$ obtained during basundi making were 12890 W/m$^2$ K and 442.3170 W/m$^2$ K at 98.1 kPa steam pressure respectively

**Table 3:** Steam side ($h_o$) and product side heat transfer coefficient ($h_i$) values obtained during manufacturing of *kheer*

| Steam Pressure kg/cm$^2$ | Batch size (kg) | $h_o$ and $h_i$ values at different scraper speed (W/m$^2$K) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 rpm ($S_1$) | | 20 rpm ($S_2$) | | 30 rpm ($S_3$) | |
| | | $h_o$ | $h_i$ | $h_o$ | $h_i$ | $h_o$ | $h_i$ |
| 1. 0 | 15 ($B_2$) | 8976.33 | 1613.62 | 8645.62 | 1827.21 | 8634.60 | 2251.53 |
| ($P_1$) | 20($B_3$) | 8480.22 | 1773.12 | 8944.15 | 1927.84 | 8281.80 | 2455.82 |

Each value is an average of two replications

## 4. Conclusion

As the study revealed, the U-value significantly increased with increase in steam pressure, batch size and scraper speed during *kheer* making in batch type SSHE. The treatment combination of 2.0 kg/cm$^2$ steam pressure, 20 kg batch size and 30 rpm scraper speed gave highest U-values of 1228.16 W/m$^2$K. However, for the performance evaluation of any machine, the quality of the product produced is also important criterion. The U-value obtained at 1 kg/cm$^2$ steam pressure, 20 kg batch size and 30 rpm scraper speed was 1197.4 W/m$^2$ K, resulted in superior sensory quality of *kheer* prepared under this combination. The $h_o$ and $h_i$ values were found to be 8281.80 W/m$^2$K and 2455.82 W/m$^2$K respectively for the same operating condition.

## 5. References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