Performance Evaluation of Three-stage Scraped Surface Heat Exchanger (SSHE) for Continuous Manufacturing of Burfi

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ABSTRACT

**Burfi** was manufactured in three-stage scraped surface heat exchanger by adding sugar directly into preheated milk by varying scraper speed in all three stages with different steam pressure in all three stages. The performance evaluation of the machine was evaluated during continuous mechanized manufacturing of **Burfi**. The average overall heat transfer coefficient were 1600, 950, and 410 W/m²K for first, the second and third stage of thin-film scraped heat exchanger (TFSSHE), respectively. The specific steam consumption was found out to be 1.12 to 0.93 kg steam per kg of milk processed with mean value of 1 kg steam per kg of milk processed. The electricity consumption was found out to be 6.0 to 8.34 KWh per 1000 kg of milk processed with a mean value of 6.83 KWh per 1000 kg of milk processed. The sensory evaluation score of the **burfi** manufactured in the SSHE was obtained 20.6 out of a total of 25.

**Keywords:** Burfi, Energy analysis, Mechanization, Performance evaluation, SSHE

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INTRODUCTION

Traditional Indian dairy products are highly valued in the society as a source of nutrition and are an inseparable part of wedding ceremonies, festivals, and religious occasions. The flavor of the new millennium is India’s ethnic milk-based sweets, desserts, and puddings (Minz PS and Shingh RRB, 2016). Many traditional dairy products, particularly khoa based sweets, Chhanna based sweets, and Paneer, have an enormous market presence and tremendous consumer base in India and overseas as well. The other popular indigenous milk products such as rabri, shrikhand, basundi, palada payasam, etc. are region specific (Dairy India, 2007). As the growth rate of the dairy industry in India is increasing, the demands for energy-efficient and highly sophisticated mechanized systems are also growing. Besides higher profitability, traditional dairy products have acquired an interest in large scale production of these products. Therefore the large scale manufacture of conventional milk products will enable the dairy plant more economically viable due to their higher profitability and export potential. It is, therefore, necessary to give top priority to work on the design and development of mechanized systems for the manufacture of traditional dairy products.

Traditional Indian Dairy Products (TIDP) accounts for over 90% of all dairy products consumed in the country. The economic significance of conventional dairy products can be realized from the fact that they have huge market size estimated of more than Rs.1000 billion; the approximate share of individual products being ghee/makkhan, Rs. 310 billion; fermented products (dahi, chaakka, shrikhand), Rs.180 billion; paneer, Rs. 20 billion and chhana and khoa based sweets, Rs 520 billion (Anon 2007). Gulabjamun, khurchan, kalakand, peda, kunda, dharvad peda, and Burfi are the main khoa based products. **Burfi** is the most popular khoa based traditional confection all over India. The generic nomenclature “**Burfi**” covers a wide range of product variations that include plain, danedar, dudh, chocolate, fruit, and coconut **Burfi**. It has variation in flavor, color, body and texture. **Burfi** is a popular milk-based sweet in which the base material is essentially khoa. Sugar is added in different proportions and other ingredients incorporated according to the demand of consumers. **Burfi** is prepared by heating a mixture of milk solids (khoa) and sugar to a homogenous consistency followed by cooling and cutting into small cubes (Khojare et al., 2003)

Even today, regardless of the volume of production, **Burfi** is manufactured primarily in jacketed kettles by halwais, which inherently suffers from several disadvantages such as low heat transfer rates, high fouling behavior, batch to batch variation in product quality, poor hygiene and sanitary conditions. The demand for efficient and labor saving processing of **Burfi** in the dairy industry attracts the application of continuous processing methods. SSHE is the
most suitable heat exchanger for handling high viscosity and heat sensitive products, which tend to foam and foul heat transfer surface (Devaraju et al., 2013). Some unique characteristics of thin-film scraped surface heat exchanger are energy conservation, suitable for heat sensitive products, high heat transfer coefficients, narrow residence time, minimum surface fouling, better to control and optimize the process.

The commercial large scale production of Burfi with very good sensory properties has necessitated sincere efforts in developing suitable equipment for the manufacture of Burfi. Looking over the performance characteristics of TFSSHE, it can also be used for the manufacture of Burfi. It has been proved very successful for the continuous production of Khoa and Basundi. The investigation is taken to explore its potential for continuous manufacture of Burfi.

**MATERIALS AND METHODS**

Experimental set-up and accessories: The experimental set up is shown in Figure 1.

**Experimental set up**

The experimental set up was three-stage scraped surface heat exchanger developed by Dodeja et al. (2007). The system includes the following components.

**TFSSHE**

The unit has consisted of three thin-film scraped surface heat exchanger (TFSSHE). All heat exchangers are identical in length, diameter, and effective heating length. The rotor assembly of the first two heat exchangers is identical but altogether different from the rotor assembly of third TFSSHE. The details of the different parts of the TFSSHE is given in Table 1.

![Figure 1: Experimental set up–three-stage thin film SSHE](image)
Table 1: Different parts of the TFSSHE

| Sr. No. | Name and details of the different parts of the TFSSHE |
|---------|-----------------------------------------------------|
| 1.      | Variable speed drives: The driven end of the scraper assembly was coupled to a variable speed drive through a flexible coupling. The drive consisted of geared three-phase, fan-cooled induction motor. The required speed adjustment was done with the help of gear units, which are splash-lubricated. With the help of these arrangements, the rotor speed of first, second stage, and third stage TFSSHE rotors as well as augur speed was adjusted from 20 to 200 rpm. |
| 2.      | Balance Tank: A cylindrical SS tank with a capacity of 250 L was used as the feed tank. It was connected to the feed pump through a SS pipe. The outlet of the pump is connected to the first TFSSHE |
| 3.      | Feed pump: Screw type ‘FAS’ Series ROTOMAC progressive cavity pump, a special type of positive displacement pump, in which flow through the pumping element is truly axial was used. The flow of milk through the pump was regulated by varying the speed of feed pump with the help of a frequency controller provided on the control panel. |
| 4.      | Valves for steam supply: Steam supply valves were provided at the inlet of each TFSSHE. |
| 5.      | Magnetic flow meter: To measure the flow rate of the working fluid, a magnetic flow meter that works on Faraday’s Law of electromagnetic induction. The Rosemount magnetic flow meter specifically designed for food, beverages, and pharmaceutical application. |
| 6.      | Pressure gauges: Pressure gauges are used to indicate the steam pressure inside the shell maintained to carry out the present investigation at different locations of the three-stage TFSSHE. |
| 7.      | I/P converter: The electro-pneumatic signal converter is used as a linking component between electric or electronic and pneumatic systems. It converts standard electric signals (mA) into standard pneumatic signals (psi or kg/cm²). Due to its innovative construction principle based on a fixed coil and a low-mass moving permanent magnet, it is highly resistant to shock and vibration. |
| 8.      | Transmitters: The transmitter was used to transmit the converted pneumatic signals from I/P converter to the controller to convey the message for the variation of process variables to optimize the whole process. |
| 9.      | Pneumatic valves: A control valve positioner is the heart of most accurate and efficient control systems, by ensuring the valve responds to the controller commands and adopts the precise position. It works on the principle of force balance to position the control valve stem in accordance to a pneumatic signal received from a controller or manual loading station. The instrument signal is applied to the signal diaphragm. An increasing signal will derive the diaphragm and flapper – connecting the stem to the right. The flapper–connecting stem will then open the supply flapper admitting supply pressure into the output, which is connected to the actuator diaphragm. The exhaust flapper remains closed when the flapper is connected to the right. The effect of an increasing signal is to increase the pressure in the actuator. When the valve reaches the position called for by the controller, the compression in the range spring will give a balancing force resulting in the closure of both the flapper. |
| 10.     | Air pressure indicators: The air pressure indicators are used to indicate the pressure supplied to the pneumatic valves to regulate the steam pressure in the cylinder shell. |
| 11.     | Digital panel meter: The digital panel meter was used to indicate the readings of rpm of all the three rotors of the three-stage TFSSHE unit. |
| 12.     | Process controller: The process controller of YOKOGAWA is an integral part of the automatic process control system assembled on the control panel of three-stage TFSSHE. It had three different modes such as operator mode (standard controller, heat/cooler controller, remote setpoint controller, profile controller), set up mode (level 2 –tuning, level 3–set points, level 4 profile) and configuration mode and is used for observing the process variable value that was attained during investigation and control setpoint value that is fixed by the operator according to the requirement so that the process variable value can’t exceed this limit. |
| 13.     | Energy meter was used to measure the electrical power consumed during the experiment. |

**Experimental accessories**

Containers: The containers were used to collect the condensate coming from each stage steam jacket to measure the steam consumption during the operation.

Others: Digital weighing balance, milk can, a milk container, etc.

**Selection of raw material**

Milk: Fresh buffalo milk and Skimmed milk was procured from Experimental Dairy National Dairy Research Institut, Karnal. Standardization was done to 6% Fat and 9% SNF. As small grains are desirable in the final quality of Burfi and grain size depend on initial acidity of the milk, the acidity of the milk has been increased up to 0.17% LA for fine grains formation in the product.

Sugar: Commercial grade white crystalline sugar purchased from the local market has been used in this present investigation.

Caustic Solution: Caustic solution of 0.75% strength was prepared by using sodium hydroxide flakes LR grade for CIP of TFSSHE.
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Water: Water available at Dairy Engineering Division was used for washing and cleaning.

Burfi manufacturing method: First, the buffalo milk was taken, filtered, and standardized to a fat 6.0% and SNF 9.0%. This milk was mixed with white crystalline sugar in the balance tank. Then the steam valves of the steam header were opened manually. The feed pump was then started, and flow was varied between 155-205 kg/h with the help of electromagnetic flowmeter by controlling the rpm of the feed pump from the control panel. The rotor blade assembly of first, second, and third TFSSHE was switched on, and the speed of all three TFSSHE’s were kept fix by a control panel. The Steam pressure was fixed in the first and second stage 4 kg/cm² and 2 kg/cm², respectively. In the third stage of the SSHE, the product contains very less moisture, which may lead to the burning of the product. So, the range of pressure 1.5 to 2 kg/cm² was kept in the third stage of SSHE. Milk was first concentrated in first stage TFSSHE and then enters into the second stage where it was further concentrated. In third stage, the steam pressure was adjusted between 1.5 kg/cm² to 2.0 kg/cm² according to observing the body of product coming to the third stage, from the second stage. The mass flow rate was adjusted to get the concentration required in the Burfi. From the third stage, a homogenous mixture of the final product was collected in well-greased plates and spreading into a thick uniform layer. Then cooling and storage was done at refrigerated temperature. When Burfi got properly cooled, it cut into pieces and analysis was done.

Analytical procedures

Analysis of milk: Initially the raw milk was tested for Organoleptic Quality, Fat, SNF and acidity by using standard methodologies

- The Fat content was determined by the Gerber method. (FSSAI, 2016)
- The SNF content was determined by the lactometer. (FSSAI, 2016)
- Titratable acidity was determined by a method described in the FSSAI manual, 2016.

Analysis of Burfi

Sensory Evaluation: The Burfi made from fresh standardized buffalo milk have typical sensory attributes, which depends on the process variables under study, viz., steam pressure, rotor rpm, type of sugar dosing method, and mass flow rate. The Burfi samples were subjected for sensory evaluation by a panel of 5–7 judges selected from the Dairy Technology and Dairy Engineering Division. A 25 point descriptive scale was used for panel of judges.

Thermal Analysis of the SSHE

Overall heat transfer coefficient: It was calculated using the following formula:

\[ Q = U \times A \times \Delta T \]
\[ U = Q / (A \times \Delta T) \]

Where \( U \) = Overall heat transfer coefficient

\( \Delta T \) = Logarithmic mean temperature difference (LMTD)
\( A \) = Heat transfer area of a cylinder
\( Q \) = Quantity of heat used = condensate flow rate \times latent heat

Steam Consumption: The condensate was collected in each stage of SSHE from the steam trap to measure the steam consumption in a different stage during the manufacture of the Burfi.

Electrical Power consumption: The energy meter was installed to measure the electrical power consumption in each scraper motor and feed pump.

Technical program: There are various process variables of three-stage scraped surface heat exchangers that were selected for the designed research project are shown in Table 2 with trial codes for the manufacture of Burfi based on factorial design. The investigation was carried out to evaluate the thermal performance of all three scraped surface heat exchangers for the continuous manufacturing of Burfi.

Results and Discussion

Effect of scraper speed on overall heat transfer coefficient

Table 3 indicates the effect of scraper speed on the overall heat transfer coefficient at a constant heat transfer area. It is evident that as scraper speed increases overall heat transfer coefficient also increases at a constant heat transfer area. It can be observed from Table 3 that U value is higher for lower scraper speed of the previous stage at a constant heat transfer area. This is because increasing scraper speed increases turbulence and hence led to higher heat transfer rates.

But increasing scraper speed of previous stage causes most of heat transfer to take in previous stage only and much more concentrated and viscous product is delivered to next stage from which evaporation rate decreases due to high concentration and viscosity. Hence it reduces heat transfer leading to comparatively lower overall heat transfer coefficient (Dodeja et al., 2012). Table 3 reveals that U Value for first stage, second stage and third stage varied from 1450 W/m²K to 1775 W/m²K; 758.36 W/m²K to 1157.71 W/m²K and 376.30 W/m²K to 451.62 W/m²K respectively.

Effect of Scraper Speed on Electric power Consumption

Table 4 indicates the effect of scraper speed on electric power consumption. It is evident that as scraper speed increases electric power consumption also increases in all three stages. It can be observed from the Table 4 that electric power consumption is higher for higher speed of previous stage. This is because increasing scraper speed increases work load on scraper motor and hence led to higher power consumption. But increasing scraper speed of previous stage causes most of heat transfer to take in previous stage only. Hence, much more concentrated and viscous product is delivered to next stage. Thus reduces the amount (volume) of product to be handled (conveyed and scrapped) which reduces power consumption (Dodeja et al., 2012).
### Table 2: Trial codes with scraper speed and steam pressure

| Trial Code | Milk flow rate (kg/h) | Scraper speed (rpm) | Steam pressure (kg/cm²) |
|------------|-----------------------|---------------------|-------------------------|
|            | 1st Stage | 2nd Stage | 3rd Stage | 1st Stage | 2nd Stage | 3rd Stage |
| T 1        | 205       | 200       | 25        | 4         | 2         | 1.6       |
| T 2        | 205       | 200       | 20        | 4         | 2         | 1.6       |
| T 3        | 205       | 200       | 15        | 4         | 2         | 1.5       |
| T 4        | 200       | 200       | 25        | 4         | 2         | 1.7       |
| T 5        | 200       | 175       | 20        | 4         | 2         | 1.6       |
| T 6        | 200       | 175       | 15        | 4         | 2         | 1.6       |
| T 7        | 195       | 200       | 25        | 4         | 2         | 1.9       |
| T 8        | 195       | 200       | 20        | 4         | 2         | 1.8       |
| T 9        | 195       | 150       | 15        | 4         | 2         | 1.6       |
| T 10       | 200       | 175       | 25        | 4         | 2         | 1.8       |
| T 11       | 200       | 175       | 20        | 4         | 2         | 1.7       |
| T 12       | 200       | 175       | 15        | 4         | 2         | 1.6       |
| T 13       | 190       | 175       | 25        | 4         | 2         | 1.8       |
| T 14       | 190       | 175       | 20        | 4         | 2         | 1.7       |
| T 15       | 190       | 175       | 15        | 4         | 2         | 1.7       |
| T 16       | 175       | 175       | 25        | 4         | 2         | 2         |
| T 17       | 175       | 175       | 20        | 4         | 2         | 2         |
| T 18       | 175       | 175       | 15        | 4         | 2         | 1.9       |
| T 19       | 185       | 175       | 25        | 4         | 2         | 1.6       |
| T 20       | 185       | 175       | 20        | 4         | 2         | 1.6       |
| T 21       | 185       | 175       | 15        | 4         | 2         | 1.6       |
| T 22       | 170       | 150       | 25        | 4         | 2         | 2         |
| T 23       | 170       | 150       | 20        | 4         | 2         | 1.9       |
| T 24       | 170       | 150       | 15        | 4         | 2         | 1.9       |
| T 25       | 155       | 150       | 25        | 4         | 2         | 2         |
| T 26       | 155       | 150       | 20        | 4         | 2         | 2         |
| T 27       | 155       | 150       | 15        | 4         | 2         | 1.9       |

### Table 3: Effect of scraper speed on 'U' value

| Trial Code | U Value (W/m²K) | Condensate Flow (kg/h) | kg steam consumed per kg Milk |
|------------|----------------|------------------------|-----------------------------|
|            | 1st Stage | 2nd Stage | 3rd Stage | 1st Stage | 2nd Stage | 3rd Stage |
| T 1        | 1657.381 | 974.0792  | 422.429   | 192.94    | 0.94      |
| T 2        | 1657.022 | 957.0927  | 416.5545  | 192.058   | 0.93      |
| T 3        | 1657.022 | 957.0927  | 390.1165  | 188.048   | 0.94      |
| T 4        | 1775.381 | 873.0266  | 437.2268  | 197.763   | 0.98      |
| T 5        | 1657.022 | 870.486   | 423.8023  | 188.048   | 0.94      |
| T 6        | 1672.955 | 882.5167  | 420.3691  | 189.879   | 0.94      |
| T 7        | 1714.161 | 847.6924  | 439.8895  | 191.405   | 0.98      |
| T 8        | 1748.617 | 855.6519  | 438.592   | 194.792   | 0.99      |
| T 9        | 1697.438 | 859.0392  | 426.7014  | 190.666   | 0.97      |
| T 10       | 1681.037 | 830.8711  | 397.7355  | 189.427   | 0.94      |
| T 11       | 1618.487 | 1008.354  | 387.0352  | 193.792   | 0.96      |
| T 12       | 1618.487 | 1008.354  | 381.8417  | 193.355   | 0.96      |
| T 13       | 1689.198 | 878.6012  | 398.2278  | 192.837   | 1.01      |
| T 14       | 1697.438 | 889.4905  | 395.2448  | 194.197   | 1.02      |
| T 15       | 1697.438 | 927.3168  | 382.9574  | 196.048   | 1.03      |
| T 16       | 1689.198 | 758.3595  | 410.1463  | 185.773   | 1.06      |
| T 17       | 1689.198 | 758.3595  | 407.1482  | 185.773   | 1.06      |
| T 18       | 1689.198 | 758.3595  | 398.1309  | 186.062   | 1.06      |

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Table 4: Effect of scraper speed on power consumption of the SSHE

| Trial Code | 1st Stage | 2nd Stage | 3rd Stage | Feed pump |
|------------|-----------|-----------|-----------|-----------|
| T 1        | 468       | 876       | 108       | 288       | 8.48     |
| T 2        | 480       | 600       | 84        | 288       | 7.08     |
| T 3        | 480       | 600       | 60        | 288       | 6.96     |
| T 4        | 480       | 732       | 114       | 276       | 8.55     |
| T 5        | 468       | 528       | 72        | 276       | 6.72     |
| T 6        | 450       | 552       | 54        | 270       | 6.63     |
| T 7        | 456       | 480       | 96        | 258       | 6.61     |
| T 8        | 456       | 480       | 66        | 252       | 6.43     |
| T 9        | 456       | 594       | 54        | 252       | 6.95     |
| T 10       | 408       | 624       | 192       | 288       | 7.56     |
| T 11       | 420       | 600       | 180       | 282       | 7.41     |
| T 12       | 420       | 600       | 156       | 288       | 7.32     |
| T 13       | 396       | 492       | 180       | 240       | 6.88     |
| T 14       | 396       | 492       | 168       | 240       | 6.82     |
| T 15       | 396       | 492       | 132       | 234       | 6.6      |
| T 16       | 408       | 408       | 168       | 204       | 6.78     |
| T 17       | 408       | 408       | 144       | 210       | 6.68     |
| T 18       | 408       | 408       | 114       | 204       | 6.48     |
| T 19       | 372       | 468       | 120       | 222       | 6.38     |
| T 20       | 372       | 462       | 108       | 216       | 6.25     |
| T 21       | 372       | 480       | 90        | 216       | 6.25     |
| T 22       | 372       | 432       | 108       | 198       | 6.52     |
| T 23       | 372       | 432       | 96        | 204       | 6.49     |
| T 24       | 372       | 432       | 84        | 198       | 6.38     |
| T 25       | 372       | 360       | 96        | 180       | 6.50     |
| T 26       | 372       | 360       | 90        | 180       | 6.46     |
| T 27       | 372       | 360       | 78        | 174       | 6.34     |

* Each value is average of three replications.

Table 4 reveals that electric power consumption for the first stage, second stage, and third stage varied from 372W to 480W; 360W to 876W and 54W to 192W respectively, and for feed pump, it varied from 174W to 288W.

Calculations for Specific Energy consumption in processing of milk during Burfi manufacturing using TSSHE

Table 5 summarizes on specific steam consumption in the processing of one-kilogram milk into Burfi. Firstly condensate flow rate was calculated for each stage, then total condensate flow rate (kg/h) was calculated by summing up condensate flow rate from all stages which was later divided by milk flow rate (kg/h) to obtain specific steam requirement (kg steam per kg milk). Specific steam consumption was found out to be 1.12 to 0.93 kg steam per kg of milk processed (Dodeja et al., 2012).

Table 5 summarizes on specific electricity consumption in the processing of milk into Burfi. Firstly electricity consumption was calculated for induction motor for scraper...
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of each stage and induction motor of feed pump, then total wattage (kW) consumption was calculated by summing up power consumption from all motors (namely scraper 1, 2, 3, feed pump motors) in kilo watts which was later divided by mass flow rate (kg/h) to obtain specific electric power consumption (kWh or Unit). The specific electricity consumption was multiplied by 1000 to get electricity consumption in terms of Unit per 1000 kg of milk processed into Burfi. Electricity consumption was found out to be 6.0 to 8.34 units per 1000 kg of milk processed (Dodeja et al., 2012).

3.4 Overall acceptability of the Burfi: Effect of scraper speed on the quality of Burfi was checked in different 27 scraper speed combinations. The scraper rpm of first, second, and third stage 150, 150, and 15 respectively found the best (maximum average score of 21.12 out of 24) for the manufacture of the product in relation to sensory quality of Burfi.

Conclusions

The performance of three stages SSHE was evaluated in different combinations of scraper speed and pressure in terms of overall heat transfer coefficient, steam consumption, and electricity consumption. The overall heat transfer coefficient increases with increase in scraper RPM, which varied from 1450 W/m²K to 1775 W/m²K; 758.36 W/m²K to 1157.71 W/m²K and 376.30 W/m²K to 451.62 W/m²K for first, the second and third stage of TFSSHE respectively. The Steam consumption increases with an increase in scraper speed, which varied from 142.45 kg/h to 116.34 kg/h; 60.6 kg/h to 39.69 kg/h and 11.82 kg/h to 8.37 kg/h for first, second and third stage respectively. The electric power consumption increases with an increase in scraper speed, which varied from 372W to 480W; 360W to 876W; 54W to 192W and 174W to 288W for first, second, third stage and feed pump motor of TFSSHE respectively. The specific steam consumption was found out to be 1.12–0.93 kg steam per kg of milk processed with mean value of 1 kg steam per kg of milk processed. The electricity consumption was found out to be 6.0 to 8.34 kWh per 1000 kg of milk processed with a mean value of 6.7 kWh per 1000 kg of milk processed. The scraper rpm of first, second, and third stage 150, 150, and 15 respectively found the best for a sensory score of the product.
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