

Heat Transfer Performance and Energy Analysis during Mathura Peda Manufactured in Mechanized Steam Jacketed Kettle

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ABSTRACT

India had emerged as the world's largest producer of milk with half of its production being used for the manufacture of different traditional milk products. For achieving uniform quality for the manufacture of these products on large scale, mechanization in production, standardization of process and processing conditions are inevitable. The performance of the mechanized steam jacketed kettle used in experiment was evaluated at different scraper speeds (S1=15 rpm, S2=20 rpm, S3=25 rpm) and operating steam pressures (P1=1.0 kg/cm², P2=1.5 kg/cm², P3=2.0 kg/cm²) by adopting optimum process of the product. The rate of evaporation ranged between 7.05 to 9.96 kg water evaporation/h and U-values ranged from 345.78 to 477.72 W/m²K. The values of steam consumption ranged from 15.75 to 20.84 kg/h and electrical power consumption 217 to 245 Wh under different operating conditions. The specific steam consumption of optimized product was found in the range of 2.09 to 2.26 kg steam/ kg water evaporated. The total heat losses during manufacture of *Mathura Peda* in the mechanized steam jacketed kettle ranged from 25.08 to 29.09 % of the heat input by the steam, at different steam pressures and scraper speeds.

Keyword : *Mathura Peda*, Mechanization, U-value, Steam Consumption, Energy Analysis

INTRODUCTION

India is the largest milk-producing country in the world. According to Basic Animal Husbandry Statistics, DAHD & F, GOI, India's milk production in 2019-20 was 198.4 million tons (NDDB, Anand). The conversion of liquid milk into traditional dairy products increases the longevity of milk solids. The consumption of sweets is an integral part of the Indian dietary system. Traditional dairy products have great commercial significance as they account for

over 90 per cent of all dairy products consumed in the country (Aneja *et.al.*, 2002).

Traditional dairy products not only have an established market in India but also have great export potential because of the strong presence of the Indian diaspora in many parts of the world (Rao and Raju, 2003). The small-scale technology adopted by halwais for the preparation of indigenous products cannot be exploited for industrial production.

Mechanization for the manufacturing of

TIDP would give large-scale production with the best possible hygienic and economical production. It would facilitate the convenient handling of both raw material and finished products. By, mechanization, it would be possible to use the same equipment's for its multiple utilization because most of the processes in TIDPs preparation consist of the same operations viz. heating, cooling, mixing, straining, pressing, and so forth with a little bit of variation in their level of process parameters. The mechanization production of value-added dairy products will give the advantages like (a) economic production, (b) uniform quality, (c) hygienic production and better keeping quality, (d) scale-up production, (e) less laborious process, (f) less energy consumption, (g) better control over the process parameters to maintain standardized sensory and rheological attributes, and (h) promote exports of TIDP through small and medium entrepreneurs. It is also necessary to develop and standardize a commercial method of manufacture of *Mathura Peda*, which can be adopted at the industrial level.

MATERIALS AND METHODS

Mechanized steam jacketed hemi-spherical kettle

In the food industry, scraped surface heat exchangers (SSHEs) are often used for improved heat transfer, crystallization, freezing and other continuous methods. They're suitable for viscous, sticky, and particulate-containing materials. SSHEs are well suited for pumpable food products and they share these traits with the vast majority of packaged foods. To facilitate control over crucial manufacturing stages,

heat-desiccated milk products such as *khoa*, *burfi*, *Peda*, *halwasan*, *halwa*, and others include batch-type SSHEs with conical or hemisphere-bottom kettle designs.



Fig 1: Mechanized Steam Jacketed Kettle

The SSHE principle is used to design the mechanized steam jacketed hemi spherical kettle. The obtained data was analyzed for the purpose of optimizing processing parameters and obtaining superior quality attributes of *Mathura Peda* in terms of its typical colour, body and texture. The highly insulated mechanized jacketed hemi spherical kettle with a volumetric size of 50 litres was used during experimentation. The kettle is made of stainless steel AISI 304. The kettle comes with all of the required attachments and mountings, including a steam pressure gauge, an air release valve, a safety valve, a steam regulating valve, a steam trap, a worm and worm wheel system for unloading hot processed products, and a lid to cover the kettle. The unit also includes a specially built scraper assembly with a Variable Frequency Drive (VFD) that allows for speed variations between 1 and 50 rpm to achieve the optimal rheological properties of the product. The scrapers are specially engineered to prevent the product from overheating and to have a higher rate of heat transfer to the desired granulations.

Table 1. Specification of mechanized system

Sr. No.	Particulars	Specification
1.	Material of construction	SS AISI 304
2.	Volume of kettle	50 liters
3.	Outer diameter of inner shell	0.500 m
4.	Inner diameter of outer shell	0.505 m
5.	Thickness of the inner shell	0.005 m
6.	Height of the inner shell (hemisphere+ cylinder)	0.450 m
7.	Effective area of heat transfer	0.3925 m ²
8.	Thermal conductivity of SS AISI 304	16.2 W/m K
9.	Thickness of steam jacket (middle shell)	0.003 m

Scraper assembly of the mechanized steam jacketed kettle

A customizable Teflon scraper blade vertical circular agitator is used in the scraper assembly. The inner shell has a 30 mm diameter 304 stainless steel shaft that is connected to a 0.25 HP gear motor via motor coupling. For improved scraper assembly speed control, the motor is attached to a variable frequency drive (VFD). To provide the required clearance to fix the Teflon blades on the stainless-steel

strip, a nut and bolt are used to modify them. The arrangement is such that the blades sweep the product settled both on the top of the inner shell and at the bottom of the hemispheric kettle. The scraper assembly includes an agitator stand at the bottom, as well as an agitator bush on the main shaft. A Teflon bush is attached to the shaft's bottom end. The angles of the two blades are maintained in such a way that the product does not adhere to them during rotating.

Table 2. Specifications of rotor and scraper assembly

Sr. No.	Particulars	Specification
1.	Type of Rotor	Teflon and SS
2.	Number of blades	2
3.	Material of strip to hold Teflon blade	AISI SS 304
4.	Blade material	Teflon

Drives for scraper assembly

The scraper assembly was powered by an A.C. motor (0.192 kW, 3-phase). For the experimental trials, a Variable Frequency Drive (VFD) was used to control the motor speed used to run the scraper assembly at various speeds.

Measuring and control instruments for mechanized steam jacketed kettle

For the mechanized steam jacketed kettle to operate efficiently, different parameters must be managed when the machine is in

operation. During the experimental trials, the VFD (Make: Amtech Electronics (India) Ltd., model: THYFREC VT130S, Capacity: 2 HP) was used to regulate the speed of the motor, which in turn regulated the speed of the scraper.

To control the steam supply to the mechanized steam jacketed kettle, a hand-operated needle valve was mounted in the steam pipe line. During use of the mechanized steam jacketed kettle, a Bourdon tube pressure gauge (range: 0 - 7

kg/cm²) was mounted on the jacket to measure the steam pressure in the jacket. A pocket-sized optical temperature sensor was used to determine the product's temperature. A power analyzer (MULTISPAN, 3-Phase 4-wire power analyzer, 440-Volt) was used to measure the electrical input variables.

Energy supply for mechanized steam jacketed kettle

The scraper assembly of the system is operated by three phase electrical motor. It is supplied with three phase connections with VFD through power analyzer. The steam is generated in the boiler was supplied to the system at required pressure by regulating the steam valve.

Process parameters for mechanized production of Mathura Peda

It was important to optimize processing variables in order to have mechanized output of *Mathura Peda*. To have greater control over the desired flavour, body and texture, colour and appearance of the mechanized system, process variables required to be optimized. In all of the experimental trials during the manufacture of *Mathura Peda*, the efficiency of the mechanized steam jacketed kettle was evaluated at various scraper speeds ($S_1=15$ rpm, $S_2=20$ rpm, $S_3=25$ rpm) and operating steam pressures ($P_1=1.0$ kg/cm², $P_2=1.5$ kg/cm², $P_3=2.0$ kg/cm²) with batch sizes of 10 litre milk. The study of energy analysis in terms of thermal and electrical calculation, overall heat transfer coefficient, energy input and output, energy losses and consumption were needed for the performance evaluation of the entire mechanized system.

Electrical Power Consumption

The electrical energy consumption (input

voltage, current and power) of the mechanized jacketed kettle was measured by power analyzer (MULTISPAN, 3- , 4-wire power analyzer, 440 volt) and energy meter installed in the electrical circuit.

Determination of Overall Heat Transfer Coefficient

The study of heat transfer was the most important aspect for designing the machines and generating data for improving the machine's operating conditions. It also aids in the selection of scraper assembly and kettle designs. The rate of heat transfer is influenced by a number of factors (i.e., the type of metal and its thickness was also affecting heat transfer performance). Steam kettles are usually hemispherical in shape, but for traditional dairy products, a flat bottom and shallow form is preferred.

Milk has been processed in a mechanized machine kettle at a lower temperature (14-16°C). It was appropriate to provide steam in the jacket for sensible heating of milk up to its boiling point in the first stage of sensible heating. As a result, the following formula was used to calculate sensible heat Q_s :

i) Sensible heating

$$Q_s = M \quad C_p M \quad (T_e - T_i)$$

Where,

Q_s = Sensible heat transfer, kJ

M = Mass of feed, kg

$C_p M$ = Specific heat of feed, kJ/kg °C

T_e = Evaporation temperature, °C

T_i = Temperature of feed, °C

ii) Latent heating

$$Q_L = E \quad L$$

Where,

Q_L = Latent heat transfer, kJ/hr

E = rate of evaporation, kg/hr

L = latent heat of evaporation, kJ/kg

As the evaporation at different stages of manufacture takes place at atmospheric conditions, latent heat of evaporation, (L) was taken as 2258 kJ/kg.

Total Heat transfer (Q_t) = Total sensible heat (Q_{st}) + Latent heat (Q_L)

Now, using heat flow equation,

$$Q_t = U A_e \Delta T$$

Where,

U = Overall heat transfer co-efficient, W/m² °C

A_e = Effective area of heat transfer, m²

ΔT = Temperature difference, °C

Thermal Energy Analysis

The mechanized system was based on mechanized steam jacketed kettle with a hemispherical bottom and scraper assembly, which was used to collect and concentrate raw materials for the manufacture of *Mathura Peda*. The concentration of the mixture was requiring different scraper speeds and steam pressures.

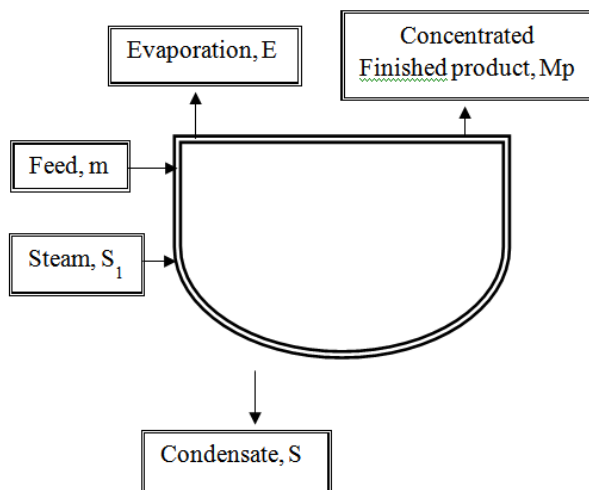


Fig 2: Block diagram of input and output energy of *Mathura Peda* manufacturing in mechanized steam jacketed kettle

Rate of heat energy input = Rate of heat energy leaving the mechanized system + Losses

$$H_f + H_s = H_c + H_e + H_p + E_1$$

$$(mf C_{pf} T_i) + S_1 (h_s + x h_L) = (S_1 C_{pc} T_s) + (E H_v) + (m_p C_{pp} T_h) + E_1$$

Where,

H_f = heat energy of feed

H_s = heat energy of steam

H_e = heat energy of evaporation

H_c = heat energy of condensate

H_p = heat energy of product

h_s = Sensible heat of steam, kJ/kg

x = Dryness fraction of steam

h_L = Latent heat of steam, kJ/kg

C_{pc} = Specific heat of condensate, kJ/kg °C

S_1 = Quantity of steam used kg/h

T_s = Saturation temperature of condensate, °C

E = Evaporation rate of water from mechanized system, kg/h

E_1 = Energy loss, kJ/h

H_v = Enthalpy of evaporated water, kJ/kg

mf = Mass of *milk* taken in kettle, kg/h

m_p = Mass of *Mathura Peda* leaving the kettle, kg/h

C_{pp} = Specific heat of the *Mathura Peda* leaving the mechanized system, kJ/kg °C

T_h = temperature of *Mathura Peda* leaving the mechanized system, °C

RESULTS AND DISCUSSION

Rate of Evaporation during manufacture of *Mathura Peda* in a mechanized steam jacketed kettle under different operating conditions

The rate of evaporation (kg water

evaporated/h) in the mechanized steam jacketed kettle during the manufacture of *Mathura Peda* at different steam pressures and scraper speeds (Table 3). During the manufacturing of *Mathura Peda*, the rate of evaporation varied from 7.05 to 9.96 kg water evaporated per hour depending on

the operating conditions. According to the details in the table, the rate of evaporation increased with the increase in scraper speed and steam pressure during the manufacturing of the *Mathura Peda*, due to the covering more effective area of heat transfer and effect of turbulence.

Table 3. Rate of Evaporation and U-values during manufacturing of Mathura Peda under different operating conditions of the mechanized steamjacketed kettle

Steam Pressure kg/cm ² (kPa)	Scraper speed (rpm)	Rate of evaporation (kg water/h)	U-value (W/m ² K)
1.0 (98.1)	15	7.05	345.78
	20	7.32	351.09
	25	7.61	364.98
1.5 (147.15)	15	7.98	382.79
	20	8.40	402.90
	25	8.63	413.90
2.0 (196.2)	15	9.02	432.70
	20	9.38	449.90
	25	9.96	477.72

Overall heat transfer coefficients (U-values) of mechanized steam jacketed kettle at different operating conditions during the manufacture of *Mathura Peda*

The overall heat transfer coefficients (U-values) during the manufacture of *Mathura*

Peda in the mechanized steam jacketed kettle were determined (Table 3). The sample calculation of the U-value for one set of operating variables is given in Appendices.

Table 4. U-values during manufacturing of Mathura Peda under various operating conditions

Steam Pressure	U - Value W/m2K			
kg/cm2	Scraper Speed (RPM)			Mean (P)
	S1 (15)	S2 (20)	S3 (25)	
P1	347.24	352.34	366.07	355.21
P2	384.36	403.90	415.78	401.35
P3	435.01	451.05	480.03	455.36
Mean (S)	388.87	402.43	420.63	
	SEm±	CD (0.05)		CV %
P	0.723	2.149		
S	0.723	2.149		0.53
P X S	1.253	3.722		

* Each value is an average of three replications

The average U-values derived from data collected under different operating conditions during the manufacture of *Mathura Peda* in the mechanized steam jacketed kettle. At various combinations of operating parameters, such as steam pressure and scraper rpm, the U-values obtained during the manufacturing of *Mathura Peda* in a mechanized steam jacketed kettle ranged from 345.78 to 477.72 W/m²K.

Statistical analysis of the data showed that the main effects of steam pressure (P) and scraper speed (S) during the manufacturing of *Mathura Peda* in the mechanized steam jacketed kettle were significant at a 5% level of significance. Steam pressure and scraper speed (PS) had a significant interaction effect. The U- value during the manufacture of *Mathura Peda* under various processing conditions of mechanized steam jacketed kettle (Table 4).

Increase in the level of steam pressure and scraper speed there was increase in the U-values. The higher scraper speed gave

higher rate of evaporation. Similar findings on overall heat transfer coefficients have been reported during manufacturing of *Halwasan*, *Burfi* and other traditional products. (Vyas, 2011).

Thermal energy requirement

Steam consumption was in the range of 15.75 to 20.84 kg/h under different operating conditions. According to the results, steam consumption increased as steam pressure and scraper speed increased during the manufacturing of *Mathura Peda* in the mechanized steam jacketed kettle.

Under various operating conditions, specific steam consumption ranged from 2.09 to 2.26 kg steam/kg water evaporated. The steam pressure and scraper speed increased and specific steam consumption decreased as well (Table 5). Increase in the speed resulted into reduction in the specific steam consumption which may be due to intense agitation and more heat penetration in the whole mass.

Table 5. Steam consumption and specific steam consumption of *Mathura Peda* manufacturing in mechanized steam jacketed kettle

Steam Pressure kg/cm ² (kPa)	Scraper speed (rpm)	Rate of evaporation (kg water/h)	Steam consumption kg/h	Specific steam consumption (kg steam/ kg water evaporated)
1.0 (98.1)	15	7.05	15.75	2.23
	20	7.32	16.07	2.20
	25	7.61	16.23	2.12
1.5 (147.15)	15	7.98	17.78	2.23
	20	8.40	17.98	2.14
	25	8.63	18.08	2.10
2.0 (196.2)	15	9.02	20.41	2.26
	20	9.38	20.62	2.20
	25	9.96	20.84	2.09

Table 6. Heat energy input, output and heat losses during the manufacture of *Mathura Peda*

Steam Pressure kg/cm ² (kPa)	Scraper speed (rpm)	Heat energy of feed kJ/h	Heat energy of steam kJ/h	Heat energy of condensate kJ/h	Heat energy of evaporated water kJ/h	Heat energy of product leaving kJ/h	Energy losses kJ/h	Energy losses (%)
1.0 (98.1)	15	573.78	37802.21	8051.31	19150.62	416.70	10757.36	28.42
	20	595.51	38570.2	8214.89	19884.05	432.48	10634.34	27.57
	25	618.96	38954.27	8296.68	20671.80	449.51	10155.24	26.07
1.5 (147.15)	15	649.65	42674.49	9089.04	21676.87	471.80	12086.43	28.32
	20	683.54	43154.52	9191.27	22817.76	496.41	11332.62	26.26
	25	701.85	43394.53	9242.39	23442.53	509.71	10901.75	25.12
2.0 (196.2)	15	734.65	48986.86	10433.48	24501.93	533.53	14252.57	29.09
	20	763.18	49490.89	10540.83	25479.83	554.53	13679.16	27.64
	25	810.39	50042.92	10658.40	27055.34	588.53	12551.04	25.08

The energy components of heat input, heat output, and heat losses. This energy components are represented in hours and showed an increasing trend as steam pressure and scraper speed increased. At different steam pressures and scraper speeds, total heat losses in the mechanized steam jacketed kettle during the manufacture of Peda varied from 25.08 to 29.09 % of the heat input as steam (Table 6).

Electrical energy requirement

The electrical power consumption of the mechanized steam jacketed kettle during the manufacture of *Mathura Peda* (Table 7). These values ranged from 217 to 245 Wh

depending on the operating conditions. The data indicates that the rise in electrical power consumption with the increase in scraper speed. The average power consumption during *Mathura Peda* manufacturing was 0.231 kWh. The mechanized steam jacketed kettle requires very little electrical power in comparison to the amount of thermal energy used. A similar observation has been reported by Bhadania (1998), Dhotre (2006), and Dodeja and Deep (2012) during the manufacture of *khoa* and thermal processing of dairy products.

Table 7. Electrical power consumption of the mechanized steam jacketed kettle during manufacture of *Mathura Peda*

Steam Pressure kg/cm ² (kPa)	Scraper speed (rpm)	Electrical power consumption Wh
1.0 (98.1)	15	217
	20	228
	25	240
1.5 (147.15)	15	220
	20	230
	25	242
2.0 (196.2)	15	224
	20	235
	25	245

CONCLUSION

It is important to introduce mechanization on sweetmeat to address the drawbacks associated with traditional technology and make it easier to adopt at a commercial scale for large production. However, no attempt at mechanized development of *Mathura Peda* has been published.

The optimum formulation of the product, the efficiency of the mechanized steam jacketed kettle used in the experiment was evaluated at various scraper speeds ($S_1=15$ rpm., $S_2=20$ rpm., $S_3=25$ rpm.) and working steam pressures ($P_1=1.0$ kg/cm², $P_2=1.5$ kg/cm², $P_3=2.0$ kg/cm²).

The U-values of the mechanized steam jacketed kettle at various operating conditions were calculated. The electrical energy consumption of the mechanized steam jacketed kettle was calculated using the power analyzer attached to the jacketed kettle, and the energy analysis of the mechanized jacketed kettle in terms of thermal energy was carried out using heat & mass balance equations.

The rate of evaporation ranged between 7.05 to 9.96 kg water evaporation/h during manufacturing of *Mathura Peda* at different operating conditions. The rate of evaporation increased with the increase in scraper speed and steam pressure.

The U-values of the mechanized jacketed kettle increased with increase in steam pressure and scraper speed during *Mathura Peda* making process. The range of U-values were about 345.78 to 477.72 W/m²K. under various operating conditions of the mechanized jacketed kettle.

The values of steam consumption and electrical power consumption under

different operating conditions during manufacture of *Mathura Peda* ranged from 15.75 to 20.84 kg/h and 217 to 245 Wh, respectively. The specific steam consumption of optimized product was found in the range of 2.09 to 2.26 kg steam/kg water evaporated. The energy components of heat input, heat output and heat losses showed increasing trend with increase in steam pressure and scraper speed. The total heat losses during manufacture of *Mathura Peda* in the mechanized jacketed kettle ranged from 25.08 to 29.09% of the heat input by the steam, at different steam pressures and scraper speeds.

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