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Influence of mechanical vapour ejector system on thermal performance of multipurpose processing vat in the manufacture of Kalakand

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Abstract
This study evaluated the effect of a Mechanical Vapour Ejector System (MVES) on the thermal performance of a Multipurpose Processing Vat (MPV) used in the manufacture of *Kalakand*. The investigation aimed to enhance heat transfer and accelerate the thermal performance of the MPV employed in producing various Traditional Indian Dairy Products (TIDPs). The performance of the MVES-integrated MPV was studied under varying air flow rates, steam pressures and scraper speeds while maintaining constant feed conditions. Results showed a significant ($p < 0.05$) improvement in evaporation rate (16.8%) and overall heat transfer co-efficient (17.8%), particularly during the concentration stage. Additionally, steam and power consumption were reduced by 13.2% and 10.0%, respectively. The proximate composition and sensory properties of the *Kalakand* were also evaluated, indicating enhanced quality in the product prepared using the MVES. These findings suggest that the MVES-integrated MPV is an efficient and energy-saving system for traditional dairy processing.

Keywords: Mechanical vapour ejector system, multipurpose processing vat, thermal performance, evaporation rate, overall heat transfer co-efficient

Introduction
Traditional Indian dairy products (TIDPs) constitute one of the largest segments of the Indian dairy industry. These products have been an integral part of Indian food culture for centuries and are consumed daily as well as during religious ceremonies, festivals, and social occasions. India, being the world's largest milk producer, contributing more than 24 per cent of the world's total milk production. India's milk production continued to increase about 6 per cent per annum, while the per capita availability registered a growth of above 4.5 per cent during the past five years (DAHD). Out of the total milk produced in India, with approximately 50-55% of its total milk production being used to manufacture a wide range of traditional dairy products, Khoa and Khoa-based sweets, chhana, paneer, shrikhand, rabri, basundi, kheer, halwa, kunda, payasam, thabdi, thabdi peda, along with fermented products and various region-specific ethnic delicacies. (Baladhiya *et al.*, 2020) [4] but traditional milk products are primarily limited to small-scale operations within the unorganized sector (Dodeja, 2014; Patel & Bhadania, 2015) [8, 15].
In Asian subcontinent, these traditional milk products are very popular. These sweets are commonly based on *Khoa* (Aggarwal *et al.*, 2018) [2]. As per Food Safety and Standards Regulations (FSSR), 2011 Khoa is the product obtained by partial removal of water from any variant of milk with or without added milk solids by heating under controlled conditions. As per Ganguli (1981) [10], Khoa is the foundation for numerous sweets and 7% of the country's total milk production converted in to khoa (Rajarajan *et al.*, 2007) [15]. Kalakand is a classic Indian milk sweet prepared by slowly simmering milk, reducing it into granular khoa added with sugar. Addition of acid (citric acid) is often used to get its distinct grainy (Badola R, *et al*, 2023) [3]. Looking at the current scenario of energy efficient operations in dairy and food industries, there is tremendous scope of improvement in the existing systems to make them more efficient. The demand for these products continues to increase due to rapid urbanization, rising disposable income, changing lifestyles, and growing consumer preference for traditional and minimally processed foods. Traditional milk products have a significant market potential in India as well as in abroad. However, several challenges

Continue to affect the traditional dairy product sector De, S. (2001). Most products are manufactured using conventional methods with limited mechanization, resulting in variations in quality, texture, composition, and shelf life. Inadequate hygienic practices, lack of process standardization, seasonal fluctuations in milk availability, and limited cold-chain infrastructure further restrict product quality and market expansion Baldha. K. G. (2019) [5].

Future prospects for traditional Indian dairy products are highly promising. Increasing consumer awareness regarding authenticity, nutrition, and regional specialties has created new opportunities for standardized processing technologies, improved packaging, geographical export promotion, and mechanization of traditional manufacturing processes. Considering the growing need for improving energy efficiency in traditional dairy product manufacture, the present investigation was carried out to evaluate the influence of the Mechanical Vapour Ejector System (MVES) on the thermal performance of a Multipurpose Processing Vat (MPV) during Kalakand manufacture.

Materials and Methods

The milk having 4.5 per cent milk fat and 8.5 per cent solid not fat was collected in clean and dry steel cans and kept at refrigeration temperature. The milk samples for chemical analysis were prepared, for that analytical grade chemicals were used in the present study (Indian Standard IS: 4883, 1980).

2.1 Experimental Set Up

The kettle with bottom jacket is known for the products having viscous, sticky product. In the present study use the Multipurpose Processing Vat (MPV) based on steam jacketed conical frustum open type kettle having volumetric capacity of 40 liter. The kettle is considered as Multipurpose Processing Vat as it serves the multiple purposes of manufacture of Khoa, Burfi, Kalakand, Rabri, Basundi and Halwa, etc. The MPV designed from AISI 316 stainless steel, was provided with all mountings like pressure gauge, thermodynamic type steam trap, steam safety valve, air release valve, steam regulating valve, worm and worm wheel mechanism for unloading of processed product and lid for covering the MPV. This vat having scrapper assembly attached with Variable Frequency Drive (VFD) to have variations of speed in the range of 1 to 50 rpm. The steam generated in the boiler was supplied to the system at required pressure by regulating the steam valve and steam pipe lines are connected with required accessories like pressure gauge, steam control valve, steam trap, etc.

The design specifications of the MPV used for present investigation are given in Table 1.

Table 1: Specification of Multipurpose Processing Vat (MPV)

Sr. No.	Particulars	Specifications
1.	Material of Construction	AISI SS 316
2.	Thermal Conductivity (K)	16.2 W/m K
3.	Diameter of Top (Inner Shell)	1.080 m
4.	Diameter of Bottom (Inner Shell)	0.736 m
5.	Thickness of Inner shell	0.005 m
6.	Height of Inner shell (Conical)	0.380 m
7.	Volume of kettle	40 L
8.	Frustum Slant Height	0.420 m
9.	Thickness of Jacket (Bottom)	0.080 m
10.	Thickness of Bottom Base	0.010 m
11.	Total Area of the kettle	1.5952 m^2
12.	Effective Heat Transfer Area of Kettle (A_e)	0.4069 m^2

In the present study use the Mechanical vapour ejector system (MVES) instead of open pan concentration. MVES was designed as per specification (Table 2) and installed to remove water vapours produced inside during milk concentration.

Table 2: Specification of Mechanical Vapour Ejector System (MVES)

Sr. No.	Particulars	Details
1.	Motor Model	CB 100836 W
2.	Rated power	25 W
3.	Voltage, Phase & Frequency	230 V, 1 Phase, 50Hz
4.	Suction port diameter (D_s)	7.4 cm
5.	Discharge port diameter (D_d)	7.5 cm
6.	Max. Static Pressure	200 Pa
7.	Rated Speed	2800 rpm
8.	Max. air flow	100 CFM

The MVES consists of a radial type of blower to create the tangential flow to the axis of shaft for vapour removal with specially designed quadrilateral hood and a base for fixing the ejector to the MPV. Various components of MVES were casing, impeller, shaft, and motor and suction/discharge ports. The temperature of milk and product at various stages were measured using infrared digital temperature indicator. MVES was fitted on the top of the MPV using circular base. Amount of vapour removal depends on the MVES air flow rate and the air flow rate controlled by the potentiometric speed controller.

2.2 Experimental process variables

The effect of MVES on thermal performance of MPV was evaluated at two different steam pressures (P1 = 98.06 kPa, P2 = 196.12 kPa), three different (0.33 rps, 0.50 rps and

0.66 rps) scraper speed and four different levels of air flow rate of MVES (0.000 m3/s, 0.0094 m3/s, 0.0188 m3/s, 0.0282 m3/s) during the milk concentration. Furthermore, experimental data were collected at specified time intervals to evaluate the heat transfer characteristics, energy consumption, and cost of the Kalakand preparation process.

2.3 Preparation of *Kalakand*

The milk was subjected to a heating and concentration using the combination of process variables in MPV employed with MVES (developed system) as well as MPV without MVES (control system). The sugar and citric acid were added in the preparation of Kalakand was procured from the local market. The process flow diagram for manufacturing *kalakand* is illustrated in Figure 1.

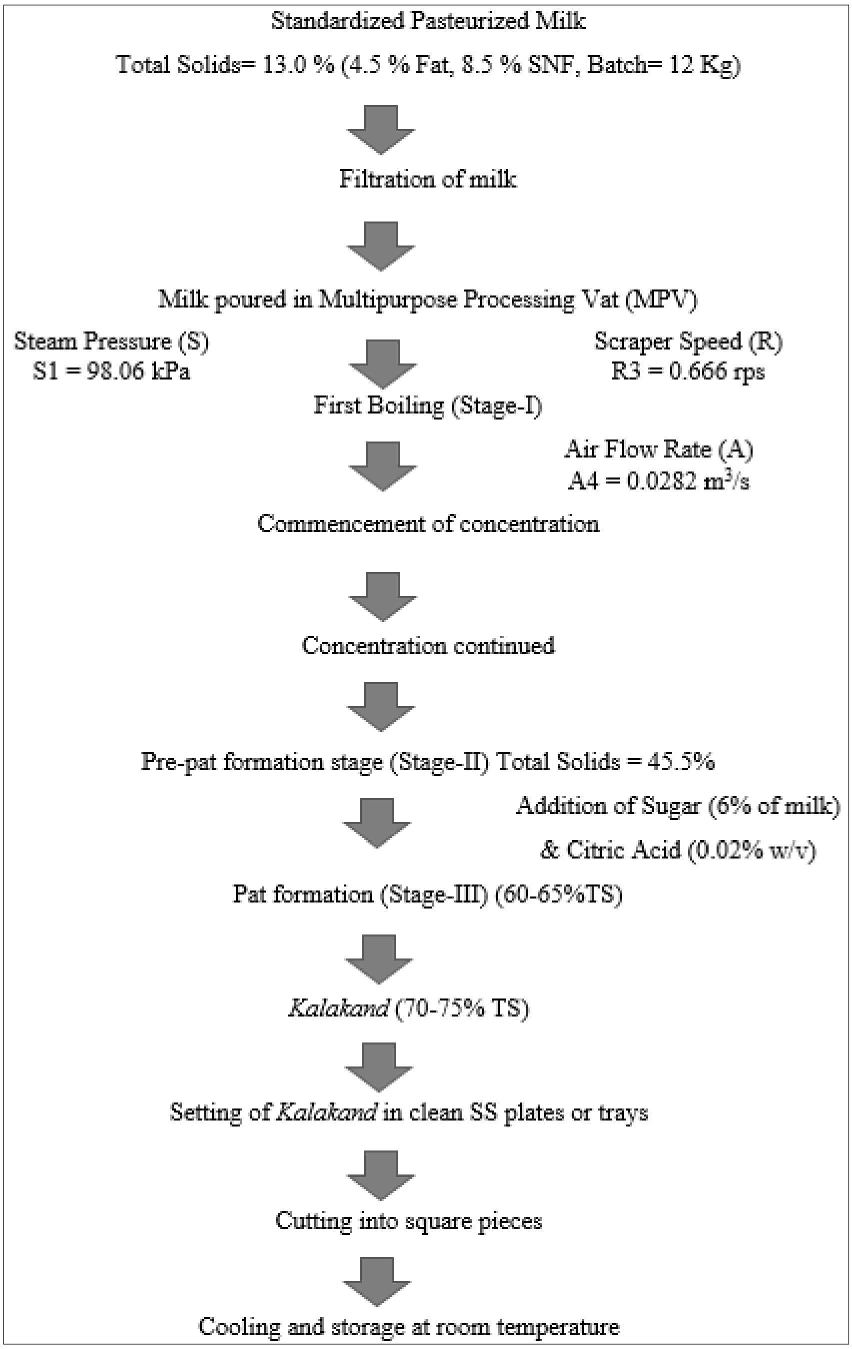

Fig 1: Process flow diagram of *kalakand* preparation

2.4 Thermal performance evaluation during manufacture of *kalakand*

The thermal performance evaluation was also carried out during manufacturing of *kalakand* using the optimized process variables in a MVES employed MPV (Developed system) and MPV without MVES (Control system). The thermal performance evaluation involved the heat transfer analysis and energy analysis, measurement and estimation of different parameters such as time for boiling, time for concentration, time for pat formation, evaporation rate, overall heat transfer coefficient (U-value for stage-I, stage-II and stage- III), steam consumption and electrical energy consumption.

2.4.1 Determination of evaporation rate

The evaporation rate was measured as kg water evaporated per hour. The rate of evaporation was calculated by Total Solids (TS) difference and mass balance. The quantity of water evaporated per hour was estimated by following equations:

$$\text{Ratio of concentration (R)} = \frac{Cf}{C} \quad (1)$$

Where,
Cf = final concentration of milk (% TS)
C = initial concentration of milk (% TS)

$$\text{Quantity of concentrated milk (P)} = \frac{M}{R} \text{ (kg)} \quad (2)$$

Where,
M =quantity of initial milk supplied for concentration (kg)
R= Ratio of concentration

$$\text{Evaporation rate } (E) = \frac{M-P}{T} \times 60 \text{ (kg/h)} \quad (3)$$

Where,
M = Initial quantity of milk taken for concentration (kg)
P= Quantity of concentrated milk obtained (kg)
T= Time required for concentration (min)

2.4.2 Time for boiling, concentration and pat formation
Time for boiling in minutes recorded as the time required to heat the milk from temperature of 10^0C to reach a boiling point. The time required to concentrate the milk from its initial total solids content of 13.0% to approximately 45% total solids (TS) was recorded as the concentration time. Upon reaching 45% TS, sugar (6% of the milk weight) and citric acid (0.02% w/v) were added to the concentrated milk. The time required to further concentrate the product from 45% TS to the final stage of pat formation (approximately 65% TS) was recorded as the pat formation time. The total processing time was calculated as the sum of the boiling time, concentration time, and pat formation time.

2.4.3 Sensible heat transfer

$$Q_S = M \times C_{pM} \times (T_i - T_p) = U A_e \Delta\theta_m \quad (4)$$

Where,
Q_S = Sensible heat transfer, (kJ)
M = Mass of feed, (kg)
C_{pM} = Specific heat of feed, (kJ/kg K)
T_p = Evaporation temperature, (K)
T_i = Temperature of feed, (K)
U = Overall heat transfer co-efficient, (W/m2 K)
A_e = Effective area of heat transfer, (m2)
$\Delta_{\theta m}$ = Log mean temperature difference, (K)

2.2.4 Latent heat transfer

$$Q_L = E \times L \quad (5)$$

Where,
Q_L = Latent heat transfer, (kJ)
E = Rate of evaporation, (kg/h)
L = Latent heat of evaporation, (kJ/kg)

2.4.5 Determination of overall heat transfer co-efficient (U-value)
According to Fourier's heat flow equation,

$$Q_s + Q_L = U \times A \times (T_s - T_p) \quad (6)$$

Where,
U = Overall heat transfer co-efficient (U-value), W/m^{2}K
A = Effective heat transfer area, m^2
Ts = Temperature of steam corresponding to steam pressure, °C
Tp = Temperature of the product, °C

2.4.6 Steam consumption
The steam consumption was estimated by measuring the quantity of condensate collected at the steam trap. At the start of trial, 3 kg water was taken in a steel can and condensate pipe was dipped into water. Water is taken in can to avoid formation of flash vapour of condensate and it gives accurate quantity of condensate. Quantity of condensate was calculated as difference of initial and final weight of can. The steam consumption was measured in kilogram (kg). The dryness fraction of steam was also estimated (X= 0.86). The total steam consumption was measured by addition of steam utilized for boiling and concentration of milk.

2.4.7 Electrical energy consumption
A three-phase electric power supply is required to operate motor of MPV agitator and a single-phase electric power supply is required for MVES. During experimental trials, VFD that has an inbuilt energy meter measured electric power consumption of agitator motor. Hence, the total power consumption is calculated as:

$$\text{Total power consumption} = P_{MPV} + P_{MVES} \quad (7)$$

Where,
P_{MPV} = Power consumed by MPV Agitator, (Wh)
P_{MVES}= Power consumed by Motor of MVES, (Wh)

2.5 Physico-chemical and sensory analysis of *kalakand*
The *kalakand* prepared in developed and control system was evaluated for physico-chemical and sensory characteristics. *Kalakand's* desired colour, flavour, body and texture were evaluated by the BIS scorecard for sensory attributes. Results of the physico-chemical and sensory attributes of *kalakand* prepared in developed and control system were analysed statistically.

Results and Discussion

3.1 Optimization of process variable for manufacturing of *kalakand*
The data of thermal performance parameters was subjected for optimization of process variables for MVES. The Design Expert 13.0 statistical analysis software was used for the optimization of process parameters. As shown in Table 3, the optimized process variables were selected based on desirability values for the further preparation of traditional milk products *viz Kalakand*.

Table 3: Optimization of process variables

No.	Steam pressure (kPa)	Scraper speed (rps)	Air flow rate (m^3/s)	Desirability
1	98.06	0.666	0.0282	0.832

3.2 Thermal Performance Evaluation of a Multipurpose Processing Vat Integrated with a Mechanical Vapour Ejector System
The thermal performance of developed system was evaluated by measurement and estimation of different parameters such as time for boiling, time for concentration, time for pat formation, total time for processing, evaporation rate, overall heat transfer coefficient steam consumption and electrical energy consumption. Evaluation of the thermal performances of the developed system (MPV employed with MVES) and control system (MPV without MVES)

were carried out using optimized levels of experimental variables and their effect was compared for the individual performance parameters as shown in the (Table 4).

As shown in the Table 4, he thermal performance parameters for control and developed system in preparation of Kalakand was carried out, the time for boiling, concentration and pat formation was reduced by 4.10%, 20.80% and 8.90%, respectively. Thus, total processing time for developed system was reduced 15.80% compared to the control system. The evaporation rate increased significantly 16.8% in the developed system compare to controlled system. Further, the U value for stage-I, stage-II and stage-III were increased 0.40%, 17.80% and 4.50% for developed system in comparison to control system. increase in the overall heat transfer coefficient for stage-II. However, for stage-I and stage-III, although slightly higher, the overall heat transfer coefficients were not significantly different for the two systems.

When comparing the systems for power consumption, the results obtained with a significant reduction in the power required for the scraper by 15.80% in the developed system as compared to the control system. Conversely, the power required for the MVES in the developed system increased (5.73% of control system) in comparison to the total power consumed by control system. However, despite this increase, the total power requirement was significantly decreased by 10.0% in the developed system compared to the control system, compensating the additional power needed for the MVES.

Further, the developed system showed the reduction in total steam consumption by 13.20% when compared with the control system. Therefore, the specific steam consumption for Kalakand preparation decreased from 5.88 kg of steam per kg of water evaporated in the control system to 5.15 kg of steam per kg of water evaporated in the developed system. The reduction in specific steam consumption was also found to be significant with a decrease of 12.40% observed in the developed system compared to the control system. The steam consumption values were reasonably higher in both systems due to the design of the MPV. The MPV features a jacketed bottom where steam condensate might get stagnated, potentially causing faster steam condensation without effectively utilizing the heat energy from the steam. It was observed that the energy losses were moderately higher in control system compare to developed system. Therefore, the specific energy consumption (SEC) was 5532.97 kJ/kg for the control system and 5231.74 kJ/kg for the developed system. Whereas, the specific energy losses (SEL) were 7027.63 kJ/kg for the developed system and 8449.75 kJ/kg for the control system.

Table 4: Comparison of thermal performance parameters for control and developed system in manufacture of *Kalakand*

No	Parameter	Unit	Control System	Developed System	P value (p<0.05)	% Change
1	Time for Boiling	min	12.33±0.29	11.83±0.29	NS	– 4.1%
2	Time for concentration	min	56±1	44.33±0.76	S	– 20.8%
3	Time for pat formation	min	20.5±0.5	18.67±0.76	S	– 8.9%
4	Total Processing Time	min	88.83±1.53	74.83±1.04	S	– 15.8%
5	Evaporation rate	kg/h	7.64±0.16	9.19±0.18	S	+16.8%
6	U Value (Stage-I)	W/m^2k	261.92±0.71	262.87±1.08	NS	+0.4%
7	U Value (Stage-II)	W/m^2k	524.9±7.21	638.3±6.19	S	+17.8%
8	U Value (Stage-III)	W/m^2k	230.1±8.07	240.99±8.92	NS	+4.5%
11	Power consumption	Wh	543.36±9.34	488.91±6.8	S	– 10.0%
12	Steam consumption	kg	57.23±1.63	49.67±0.42	S	– 13.2%

Control System= MPV without MVES, Developed System= MPV employed with MVES
Each observation is an average of three replicate experiments (n=3),
S = significant and NS= Non- significant

3.3 Effect of MVES on physico-chemical characteristics of *kalakand*

A *kalakand* sample from the whole batch was taken as per the procedure described in Indian Standard: 2785-1964 (Indian Standard, 1981). The proximate analysis of chemical composition for *kalakand* such as moisture content, protein, fat and ash were determined according to AOAC (AOAC, 2005) standard method. While the total carbohydrate content was determined by difference. Further, the method prescribed by (Deeth *et al.*, 1975) [7] was used to estimate the Free Fatty Acids (FFA) content of *kalakand*. While, the Titratable acidity of *kalakand* was determined by the procedure as described in BIS: Part XI, 1981.

Table 5: Comparison of physico-chemical characteristics of kalakand prepared by control and developed system

No.	Parameters	Control Sample	Experimental Sample	P value (p<0.05)
1	Moisture (%)	23.15±0.29	24.58±0.47	NS
2	Fat (%)	23.51±0.73	24.47±0.43	NS
3	Protein (%)	16.78±0.30	15.31±0.68	NS
4	Total Carbohydrate (%)	33.29±0.80	32.29±0.91	NS
5	Ash (%)	3.27±0.24	3.35±0.26	NS
6	Free fatty acid (%oleic Acid)	0.48±0.01	0.48±0.01	NS
7	Acidity (%LA)	0.64±0.09	0.63±0.04	NS

Each observation is an average of three replicate experiments (n=3)
S = significant and NS= Non- significant

The moisture (23.15%), fat (23.51%), protein (16.78%), total carbohydrate (33.29%), ash (3.27%), FFA (0.48% OA) and acidity (0.64% LA) was found for control sample of *Kalakand*; While experimental sample of *kalakand* shown the moisture (24.58%), fat (24.47%), protein (15.31%), total carbohydrate (32.29%), ash (3.35%), FFA (0.48% OA) and acidity (0.63% LA), respectively. It is revealed from the data that there is no significant (p>0.05) difference observed between the composition of control and experimental samples (Table 5).

3.4 Effect of MVES on sensory attributes of *kalakand*

The *kalakand* was analyzed using 100-point sensory score card as per BIS (1980). The body and texture score for *Kalakand* prepared in developed system has no significant difference with the control system. It was observed that, body and texture of prepared *Kalakand* was pasty with slightly moist body and smaller grains in both the systems. Both the samples were found to have pleasant taste and optimum sweetness as reported by panel of judges. Further, the flavour score remained identical for both the types of sample. It was perceived that the *Kalakand* prepared in control system as well as in developed system had a slightly caramelized flavour. The total sensory score of the *Kalakand* prepared in developed system was found more than that of *Kalakand* prepared in the control system. The average sensory scores of *kalakand* is presented in Table 6.

Table 6: Comparison of sensory scores of kalakand prepared by control and developed system

No	*Khoa*	Score	Control Sample	Experimental Sample	P value (p<0.05)
1	Colour & appearance	(15)	11.04±0.7	13.85±0.53	S
2	Body & texture	(30)	30.19±1.67	31.2±1.77	NS
3	Flavour	(50)	39.67±1.69	40.14±0.79	NS
4	Total score	(100)	85.9±2.98	90.2±2.04	NS

Total score includes score of 5.0 for package
Each value is an average of three replicates (n=3),
S = significant and NS= Non- significant

Conclusion

In the present study, the effect of MVES on thermal performance of MPV was evaluated during manufacture of *kalakand*. The various levels of steam pressure, scraper speeds and air flow rates were investigated. From the data, the optimized operating combination was identified as 98.06 kPa steam pressure, 0.666 rps scraper speed and 0.0282 m^3/s air flow rate. Compared to the conventional MPV, the MVES-integrated system significantly improved thermal performance, reducing total processing time by 15.8%, The evaporation rate increased significantly 16.8% in the developed system compare to controlled system. Further, the U value for stage-I, stage-II and stage-III were increased 0.40%, 17.80% and 4.50% for developed system in comparison to control system. It also achieved a reduction in power and steam consumption by 10% and 13.2%, respectively. While physico-chemical properties of kalakand founds no significant difference control and in the MVES system. Thus, MPV employed with MVES could be effectively used for the manufacture of heat desiccated traditional milk product, *kalakand* with reduced energy requirements, lower processing times, lower total costs and improved sensory attributes.

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