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Quality *Dahi* Preparation in Automated Controlled Ambient Conditions

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Abstract

This automated controlled system eliminates the need of two separate places for incubation of the curd at higher temperature in the range of 39 to 43°C and then shifting the set curd cups into cold rooms for storage purpose and kept at about 4 to 5°C.The transient cooling process of *dahi*, set in cups and also in steel containers placed in cold air flow was conducted in this experimental study. Recording of the temperature of *dahi*-cups and of the supplied air were done at regular intervals until the temperature reached below 4°C to 5°C. The exponential curves of cooling by forced convection process for the dimensionless temperature of curd were obtained for the trials conducted at the different velocities of cooling air flow. It was found that the surface heat transfer coefficient increased and duration of cooling decreased by increasing the air velocities from 0.5 m/s by evaluating the Biot number and surface heat transfer coefficient. In the initial period of cooling this pattern was more effective and reduced for higher velocities of air from 3.5 to 4.5 m/s. The method of incubation and storing *dahi*-cups at the same place and changing the ambient temperature of the whole environment instead of changing the place of *dahi*-cups for cooling purpose have been applied in this research work to control the problem of whey-off in set-curd.

Keywords: *Dahi*, transient cooling, cooling coefficient, heat transfer coefficient

1. Introduction

In the Indian sub-continental climate, the dairy products, including *dahi*, provide a supportive environment for rapid growth of various kinds of microorganisms. Hence, there is a necessity of cooling these products to the temperature of 3 to 4°C for their longer duration preservation with adequate good quality. The temperature of the set-curd, after its fermentation, is to be maintained at low value; otherwise many undesirable phenomena occur in it, such as the whey-off, uncontrolled growth of microorganisms causing whey syneresis, poor texture and the generation of sour flavour (Tamime and Deeth, 1980; Ramaswamy et al., 1982; Benezech and Maingonnat, 1994; Reddy, 2000; Kunal and Prajapati, 2012). The phenomena of wheying-off occur very often in set-*dahi*as and when they are mechanically disturbed and shaken during the transfer from one place to another e.g. the incubation room to the cold room for storage. This happens in almost all kinds of fermented products in a large scale production units due to the mechanical disturbances caused in their shifting process. In the local markets, significant amount of *dahi* is produced mainly by *halwais* (local manufacturers) at sweets and milk shops and small and medium scale dairy farmers. In the production of

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yogurt, the cultured milk cooling can start only once when acidification has been reached to a pH of 4.4-4.6. Hussain et al. (2016). Talbot et al. (2019) studied pH effect on the physio-chemical, microstructural and sensorial properties of processed cheese manufactured with various starches. Tang et al. (2017) studied the effect of pH on lactic acid production from acidogenic fermentation of food waste with wide variety of inoculum. The texture of the product and propensity to syneresis (serum separation) are the main characteristics that define the quality of yogurt (Lee et al., 2010). Bhadoria and Mahapatra (2011) discussed the importance of nutritional and health benefits (antimicrobial activity, improving lactose metabolism, reduction of serum cholesterol, increase in body weight, stimulation of immune system, antimutagenic effects, reestablishing the normal flora in small intestine, anticarcinogenic properties, etc.) of probiotic cultures such as *Bifidobacterium* spp. And *Lactobacillus acidophilus* or dairy products containing these cultures and on the technological characteristics of these organisms. Recently, several dairies have begun producing and marketing *dahi* on a large scale. Entrepreneurs especially start-ups often face difficulty in availability of small capacity equipment. In order to design an efficient and effective cooling system for the products it is necessary to analyze the transient heat transfer during cooling (Dincer, 1993; Dincer and Genceli, 1994; Dincer, 1995). *Dahi* is a fermented milk product that is similar to yogurt, and is consumed by people throughout the Indian subcontinent and many other countries like Bangladesh, Pakistan, Nepal and Bhutan. It is one of the most popular Indian traditional products containing various strains of lactic acid bacteria (LAB). The preparation of *dahi*involves the fermentation of milk by a small portion of culture containing microbes of a previous fermentation (back slopping). However, production of *dahi* with an individual culture of*Lactococcuslactis*or a combination of cultures containing *lactobacilli* and *lactococci* was reported by Yadav et al. (2006). In India about seven percent of the total milk produced is used for *dahi*preparation (Kunal and Prajapati, 2012). *Dahi* accounts for around 90% of the total cultured milk products produced in India. *Dahi* is mostly used for direct consumption throughout India and it is the part of daily food in India because of its therapeutic value. Maintaining cold temperature of dairy products not only increases their shelf life but also improves its texture, which is an important parameter for consumer acceptability. Ice cream, butter, *dahi*etc are some of the dairy products whose texture improves when they are preserved and maintained at cold temperature between 0 to 5°C. In order to maximize the efficiency of cooling and freezing operations for foods, optimum design of the refrigeration equipment is necessary which must also fit the specific requirement of the particular cooling and freezing application. In order to design such refrigeration equipment, estimation of the cooling and freezing time of the food as well as corresponding cooling load is required. The accuracy of these estimates in turn depends on the accurate estimation of the surface heat transfer coefficient of food items during cooling or freezing (Becker and Fricke, 2004). The method of incubation and storing *dahi*-cups at the same place and changing the ambient temperature of the whole environment instead of changing the place of *dahi*-cups for cooling purpose have been applied in this research work to control the problem of whey-off in set-curd.

2. Materials and Methods

The quality of *dahi* can be reasonably improved if it is cooled at a faster rate immediately after incubation, as reported by many researchers. The present research was undertaken to overcome the major problem associated with *dahi* that the rapid deterioration of its quality and reduction of its shelf life is caused due to frequent microbial contamination and the microbial contamination of *dahi* becomes a major concern for health of the consumers (Aziz, 1985). In this automated technique, the immediate benefits are that the overall equipment cost is reduced, since the transportation of the product from incubation room to cooling room is not required and there is the provision of an automatic conversion mechanism from heating to cooling mode at one place only and the experiments were conducted during the year 2020-2021.

2.1. Milk

Fresh raw buffalo whole milk and skimmed milk were procured from the Experimental Dairy of the National Dairy Research Institute (NDRI), Karnal.

2.2. Starterculture

The mixed starter culture ST-600 and ST-800 (*Streptococcus thermophilus* and *Lactobacillus bulgaricus*) were obtained from the National Collection of Dairy Cultures, NDRI, Karnaland the experiments were conducted during the year 2020-2021. The starter culture was maintained in autoclaved reconstituted skimmed milk (1 g 20 l^{-1}) by sub culturing once in a fortnight for attaining high activity. During the experimental work, the buffalo milk was heated to 90°C for 15 minutes, then cooled to 45°C and inoculated with ST–600 (0.005%) culture, filled in 200 ml cups for trials at 42°C in incubation and humidity chamber for 330 minutes. The cups were kept on the wire mesh in different ratios and different positions. PT- 100 sensors with an accuracy of ±0.1°C were embedded at different positions according to air flow and according to cup's dimensions. All these temperature sensors were connected to a multichannel universal scanner/logger of Counteronics make to scan the temperature data at regular time interval of one minute.

The experimental trials were conducted for forced air cooling of curd cups exposed to same air velocity and same direction of air flow. In each trial, immediately after incubation, cooling was started until the temperature of curd reaches to 5°C. The time value during the process was measured using a digital timer meter. Immediately after the incubation period is over, the cooling is start by specially designed cooling duct provided inside the incubator and humidity chamber. The same procedure was followed for each of the trials.

2.3. Experimental set up-incubator

Incubator in one of the finest quality milk processing equipment used prominently is food processing & dairy industries. It is milk processing equipment used for speeding up the bacterial fermentation process if the milk which results in yogurt or *dahi*. Yogurt is further processed to make many other products like Ghee, shrikhand etc. *Dahi* incubator/ Yogurt Incubator a milk processing equipment that follows a simple process for making *dahi* or yogurt where in the milk is boiled and then cooled to the room temperature. This cooled milk is then mixed with bacterial culture which is used for the milk fermentation. After the thorough mixing of the milk it is then filled in the plastic cups and incubated to 30°-35°C for about 2 to 4 hrs. Forced convection system ensures good mixing, strong dispersion and maintains higher temperature uniformity inside the chamber. Synthetic door gasket made of neoprene on the double walled door. User oriented design of shelves makes you adjust each space of shelves without difficulty. Space between inner chamber and outer wall is filled with high grade insulation for minimal heat dissipation. The automated yogurt/*dahi* making set-up was used as shown in the block diagram in Figure 3 and Figure 4 and once it is loaded with pre-filled cups and switched on, it would automatically control the temperature all through the incubation period and switch over from heating to cooling mode and then would switch off automatically after the curd attaining the required low temperature. Thus, the incubation and blast air cooling of *dahi* cups were done in the same set-up. The temperature measurement was conducted by using PT100 temperature sensors connected to a digital temperature logger to measure the product as well as air temperature during the whole process. Perforated wooden blocks were prepared and placed over the *dahi* containers to insert the PT100. The PT100 sensors were embedded into *dahi* up to a depth of half of the height of the cylinder. One was embedded at the centre of the cup and another at periphery touching the inside surface of cup. Two other sensors were kept at the inlet and outlet of the cooling chamber to measure the inlet and outlet temperature of cooling air respectively. Further, the temperature profile during cooling of *dahi* in cup (200 ml) kept in still cold air at 4°C inside the cooling cabinet was evaluated by the temperature sensors placed inside the *dahi*-cups as depicted in the block diagram in Figure 2. The cooling conditions were varied in terms of i) cooling air velocity ii) flow direction and iii) use of cold water as the cooling medium. The temperature sensors used for 200 ml *dahi* cups, were of the length of 65mm and diameter of 5mm for measuring the temperatures at the various points inside and outside of *dahi* cups. Before applying, all these PT100 temperature sensors were calibrated with the standard mercury thermometer in the range of 0 to 100°C. For calibration purpose of the temperature sensors at 0 and 100°C, ice and boiling water were used respectively. There was no error observed in the process of calibration. The PT100 temperature sensors were used to measure temperature at any instant of time and were connected to an 8 channel universal scanner logger, as shown in Figure 2.Culture was added to bulk milk. The entire experimental setup was installed inside walk in cooler.

2.4. Computation of various heat transfer parameters

2.4.1. Biot number

Ratio of conduction to convection resistance, the Biot number (ratio of conduction to convection resistance) was calculated from the observations by using following equation.

Biot number = (hl / k) ....(1)

Where, h= convective heat transfer coefficient (W/m^2°C),

l= characteristic length (m),

k= conductive heat transfer coefficient (W/m°C).

The experimental data were used in plotting the result as depicted in Figure 1 and Figure 2 and the experiments were conducted in the setup as shown in the block diagram in Figure 3 and Figure 4. Fricke and Becker(2002) described a method to determine the surface heat transfer coefficient of a food product with an internal temperature gradient involving the use of cooling curves. Central temperature of

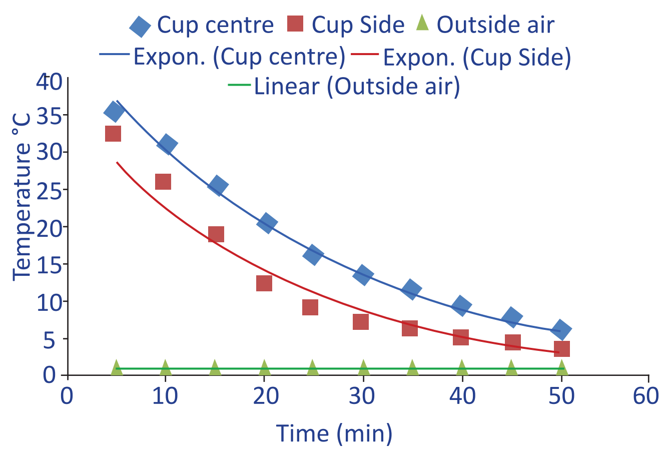

Figure 1: Temperature profile during cooling of *dahi*

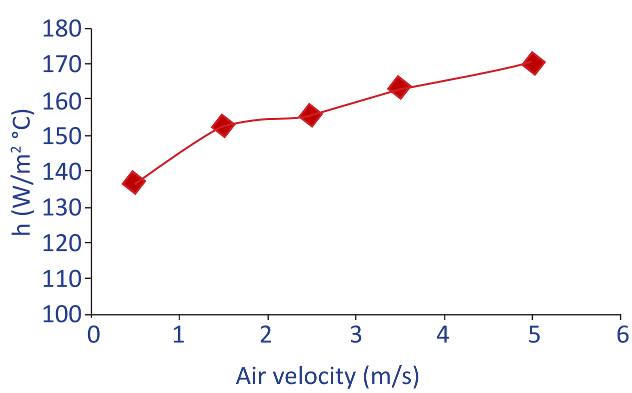

Figure 2: Variation in the value of surface heat transfer coefficient, h (W/m^2 °C) at different air velocities

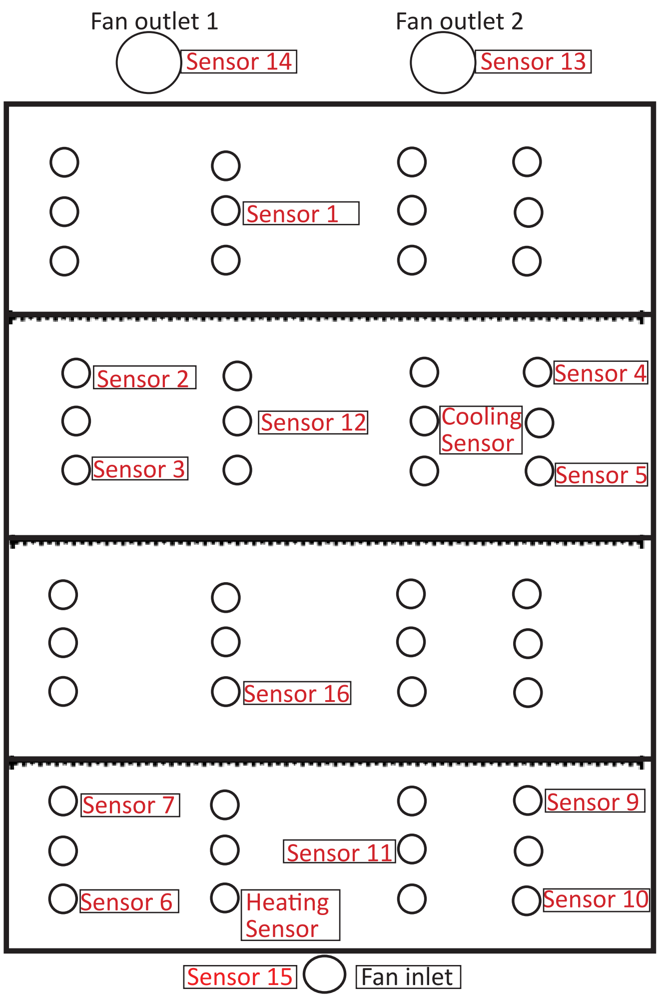

Figure 3: Layoutof the set-up developed for placing PT100 temperature sensors for evaluating the temperature profile during incubation and cooling of *dahi*

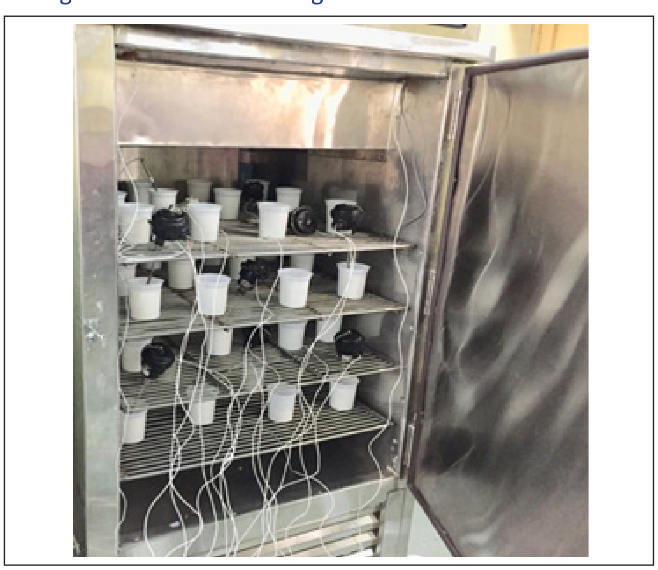

Figure 4: Sensing temperature of *dahi* by placing temperature sensors in *dahi* cups and the cooling fans placed on the top used for effective forced convection process

the individual product was measured and the dimensionless temperature values were obtained using coolant temperature and measured temperature of the product. Then regression analysis using least square method was done to obtain dimensionless temperature in exponential form. The slope of the cooling curve may be used in conjunction with this solution to obtain Biot number for the cooling process. The heat transfer coefficient was determined from the Biot number. Delgado and Sun, (2001) shown about the Heat and mass transfer models for predicting freezing processes.

2.4.2. Thermal diffusivity (α)

The process of heat transfer inside *dahi* cupswas analyzed, which is due to the temperature gradient caused by forced convection process. Thermal diffusivity of *dahi* molecules inside *dahi* cups due to forced convection plays major role in heat transfer process which can be defined as the thermal conductivity divided by density and the specific heat capacity at constant pressure. Thermal diffusivity measures the rate of transfer of heat in *dahi* cups from the hot side to the cold side. It has the SI derived unit of m^2/s. Thermal diffusivity is usually denoted by,

$\alpha = (k/\rho.c_p)$ ....(2)

Where, k is thermal conductivity in (W/ (mK))

c_p is the specific heat capacity in (J/(kgK)) and ρ is the density (kg/m^3).

Together, the temperatures ($\rho.c_p$) can be considered the volumetric heat capacity (J/ (m^3 K)). Thermal diffusivity is the rate at which heat is distributed in a material or inside *dahi* cups. It is the ability of the material to conduct thermal energy relative to its ability to store thermal energy.Also the transient heat-conduction inside the *dahi* cups follows the three-dimensional heat-conduction equation for rectangular co-ordinates, also known as the diffusion equation or Fourier equation as follow:

$(\partial^2T/\partial x^2)+(\partial^2T/\partial y^2)+(\partial^2T/\partial z^2)=(\partial T/\alpha\partial t)$ ....(3)

Where, ∂x, ∂y, and ∂z are the three dimensional elements in x, y and z co-ordinates respectively and T is the temperature.

The effect of waterand temperature on the thermal diffusivity is given below.

$\alpha=0.057363\,m_w+0.0002888(T+273)*10^{-6}$.............................(4)

Where, m_w is the moisture content of the food.

The following equation to find the thermal diffusivity of the food product was recommended by Riedel (1969),

$\alpha=0.088*10\text{-}6+(a_w-0.088*10-6)\,m_w$ ....(5)

Where, a_w is the water activity and m_w is the moisture content of the food.

2.4.3. Surface heat transfer coefficient (h)

The mode of heat transfer between solid food product and external medium is by conduction inside the food and by convection at its surface. The knowledge about the surface heat transfer coefficient is necessary for equipment designing wherein convective heat transfer is used to process the food. Surface heat transfer coefficient (h) is given by Newton's Law of cooling,

Q=h A Δt ....(6)

Where, A is the surface area (m^2) and t is the temperature difference between the food product and the fluid medium. h is a local phenomenon which depends upon velocity of the surrounding fluid, geometry of the product, orientation, surface roughness, packaging and many other factors. Transient method was used to determine Surface Heat Transfer Coefficient (h). It involves the measurement of product temperature with respect to time during cooling. It involves two conditions; one is low Biot number (Bi<0.1) and the other is large value of Biotnumber (Bi>0). Large value indicates more is the internal resistance, which means temperature gradient exists within the product and smaller value indicate low resistance to heat transfer (Becker and Fricke 2004).

3. Results and Discussion

In the developed system, the manual intervention in the whole process of curd making had been reduced to the lowest level and it was observed that when the cooling time was too long, average value of surface heat transfer coefficient was also reduced and becomes too low. In this process cooling starts immediately after the incubation period is overat the same place without disturbing the product and in this case, there is no manual intervention in the whole process of *dahi* making. For the calculation of the Biot number and heat transfer coefficient the transient temperature measurement method was used from the experimental cooling curves as shown in Figure 1 and Figure 2 obtained from the experimental results.

It was observed that the conduction resistance inside *dahi* cup was not negligible since there was significant temperature difference from centre to circumference of the *dahi* cup. This effect may be due to the reason that inner heat transfer resistance of curd remains unaffected by air velocity as evident from values obtained for Biot number which was between 4 to 5. Therefore, the velocity of air in higher range was applied in forced cooling which could become very useful in reducing the overall processing duration and enhancement in quality of the product. The obtained temperature profiles were found to be non-linear as shown in the three curves of Figure 1 and inside the cups the temperature of curd was found to be gradually decreasing during the process of cooling of *dahi* cups. The ambient temperature, outside *dahi* cups, remained almost constant at about 4°C when the cooling system started automatically after the completion of incubation period; hence the linear graph was produced as the shown straight line. It was further observed that the molecules of *dahi* particles, near the wall of cups, reached the temperature of less than 10°C within an approximate period of less than 60 minute whereas, *dahi* particles and molecules placed at the center of cups took maximum duration of about 180 minutes in reaching the temperature of less than 10°C as also depicted by the curves shown in Figure 1. This significant difference in time in reaching the low temperature is due to the significant effect of conduction resistance inside *dahi* cup within *dahi* particles and molecules and the effect of thermal diffusivity. The molecules of *dahi* particles near cup wall stabilized to lower required storage temperature of *dahi* in less than half duration than the centrally located molecules. Biot number (ratio of conduction to convection resistance) calculated from experimental data of cooling of 200ml *dahi* cup was found in the range of 4.97 to 5.31 as shown in Table 1, which shows that the conduction resistance inside *dahi* cup was not negligible as there was significant temperature difference from centre to circumference of the *dahi* cup. The direction of air flow also affected the value of convective temperature coefficient which was found as 170.06 W/m^2 °C in the case of radial direction of air flow; whereas it was reduced to 160.20 W/m^2 °C when the direction of air flow was changed to axial. It would improve and ensure the consistent quality and also reduce the product formation time and handling cost. The Figure 2 depicts the variation in the value of surface heat transfer coefficient, h (W/m^2 °C) at different air velocities varying between 05 m/s to 5 m/s. It was found that the value of surface heat transfer coefficient, h was consistently increasing with the increase in air velocity, which is actually due to rate of increased cooling, as also shown by Alfonso et al., 2003. The temperature profile characterization during cooling of *dahi*cup (200ml) in cold air flowing at 4m/s inside walk-in-cooler was done and the salient findings were observed that the cooling time decreased significantly in the moving air due to higher value of convection heat transfer coefficient as also depicted in the Figure 1. Conduction resistance inside *dahi* cup was not found to be negligible and the Biot number was evaluated and found as 6.35. The higher value ofBiot number depicts that both conduction as well as convection resistances are significant in the process of *dahi* cooling and none of them can be neglected. Table 2 shows the difference of cooling medium in the cooling process of *dahi* cups.

Table 1: Cooling process parameters of individual curd cup at different air flow directions

Direction of air flow	j	C ×10^{-4} (s-1)	Z (s)	S (s)	Biot number (Bi)	h (W m^{-2} °C)
Radial	1.084	5.47	1431	3968	5.31	170.06
Axial	1.139	4.80	1709	4581	4.97	160.20

Dahi cups were placed for cooling in the path of cold water flowing from cold source of water stored with ice cubes. The water was circulated back to the storage tank filled with ice cubes by pumping action. It shows that the cooling by applying the water is certainly better than air as the surface heat transfer coefficient increased by approximately 50% which decreased the cooling time. The rate of change of temperature

Table 2: Cooling process parameters of individual stainless Steel *dahi* cup cooled by flow of water and air

Cooling medium	Half cooling time (Min)	Seven-eight cooling time (Min)	Actual-time taken (Min)	Biot number (Bi)	h (W/m^2 °C)
Water	31±3	86±1	85±0.0	4.3±0.05	163.45±2
Air	66±5	189±10	215±0.0	3.39±0.0	109.27±3

is an important parameter as far as the textural quality of *dahi* and similar product is concerned. The effect of varying rate of heating was observed by many researchers. Dhotre and Bhadania (2017) have worked on the effect of thermization on the chemical composition, sensory acceptability of shrikhand during storage at ambient temperature and did not find any significant change, but thermized shrikhand was found to have better body and texture than control. Kim and Bhowmik (1997) worked on yogurt and calculated the value of thermal diffusivity of yogurt at different moisture content at 25°C. Mitra (2016) determined the thermal diffusivity of basundi mix as 0.101 mm^2/s at 3% moisture using KD2 Pro thermal properties analyzer. Fernandes et al. (2006) had studied the thermal behaviour of stirred yoghurt during cooling in plate heat exchangers and Raghavendra et al. (2017) utilised the concentrated paneer whey to prepare good quality *dahi* and shown that the rate of change of temperature has significant role in the body and the texture of *dahi*. When cold water passed through *dahi* cups, the rate of temperature decay was higher than in the case of passing of cold air. This developed method could easily be applicable and adaptable to small and medium scale *dahi* producers and farmers. The improved quality of product may be obtained due to auto start of blast cooling after incubation without any delay and also the rapid production occurs without any human intervention. Various kinds of *dahi* making cabinets (*dahi* incubators) available in the market are being used by the local level manufacturers at small and medium scale, but their cost is one of the main constraints and at the same time the fully automatic machine at small and medium scale is not available for *dahi*. The automated system could be useful for small and medium entrepreneurs for *dahi* production in sealed of cups in ready to use form. This technique of *dahi* making machine would fetch automatic, energy efficient, hygienic, and economic solution for production of good quality *dahi* with controllable process parameters. By this developed technology, a much better profit for the stakeholders involved in small scale yogurt/ *dahi* production and processing is possible, only single equipment could be used for both the operations of incubation as well as rapid cooling. In the conducted experiments, the size of the set-up is small and limited but the same developed technology can very well be upgraded for medium to the larger amount of product handling.

4. Conclusion

In the developed controlled incubation system, the incubation and storage of the curd cups are performed at the same unit, so that the causes of mechanical disturbances could be eliminated completely in shifting the set curd from incubation chamber of curd, consequently improving the income of the dairy entrepreneur. During the curd preparation conduction resistance inside curd cup is not negligible as there is significant temperature difference from centre to circumference of the curd cup. Biotnumber calculated from experimental data was found low as less than 2.8. Overall quality of the curd improved significantly by using the automated technique.

5. Acknowledgement

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