Comparative study on phase changing material for refrigeration effect for milk chilling

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Abstract: In developed countries the milking collection is done to process in various diary plants situated far away from production areas. There is a problem of cool chain management, which, generally is absent at farm levels. To manage the cool chain in milk transportation system right from farm level it is required that some locally available techniques/materials should be selected and used for milk chilling. The objective of current study is to ascertain mechanism for chilling of milk at farm immediately after milking. The experiments were conducted and the cooling performance was evaluated by noting down the drop in temperature with respect to time using mercury thermometer. The respective regression equation and R^2 value were obtained for every run of the experiment. It was observed that the relation between temperature drop and time was significant for coolant to product ratio of 1:3 & 1:2 under insulated condition (p<0.05). The study showed that the cooling of milk can effectively be done by immersing the ice packs in milk by using ice to product ratio in range from 1:3 to 1:2 under insulated condition within the recommended time as per standards.

Keywords: PCM, ice, milk, insulation, temperature drop, time

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1 Introduction

Phase Change Materials (PCM) is a latent heat storage material. According to Lane (1983), latent heat storage is a relatively new area of study and pioneered by Telkes in the 1940s. As the source temperature rises, the material changes phase from solid to liquid due to the fact that the chemical bonds within the PCM break up (as is the case for solid-liquid PCMs which are of particular interest here). The phase change is an endothermic, i.e. heat seeking process and therefore, the PCM absorbs heat. After attaining the phase change temperature, the material begins to melt and the temperature then stays constant until the melting process is finished. The heat that gets used up during the phase change process of the material is called latent heat. The effect of latent heat storage has two main advantages. Firstly, it is possible to store large amounts of heat with only small temperature variation and therefore to have a high storage density, secondly, it is possible to smoothen the temperature variations as the phase change process at a constant temperature takes some time to complete. Latent storage materials store 5 to 14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock (Abhat, 1978). A large number of PCMs are known to melt with a heat of fusion in any required range. A study by Hale et al (1971) & Budhi and Sawhney (1994) reported that PCM to be used in the design of thermal storage systems should possess desirable thermo physical, kinetics and chemical properties.

The most common storage media for cooling are water, ice and PCMs, commonly known as eutectic salts. PCMs have been used for various heat storage applications since the 1800s, but they are recently being

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used as a storage media for space cooling. For cool storage, most of the PCMs are inorganic salt hydrates, organic paraffin waxes and mixtures of these. Literatures available on thermal storage at a temperature below the ambient, other than for ice are limited (Solmar et al., 1989). Bo and Seterwall (2002) studied the potential for using cool storage systems using PCMs through the static and dynamic cool storage processes. The following systems have been proposed for cooling with thermal energy storage using PCM which shows phase change at lower temperatures below 30°C (Salyer and Sircar, 1989; Feldman et al., 1995; Inaba and Sato, 1997; Yamaha et al., 2001; Zalba et al., 2004; Nagano et al., 2004; Takeda et al., 2004).

Ice is an efficient heat carrier due to the latent heat of ice crystals. The high heat transportation capacity of ice slurry and its low operating temperatures make it an excellent alternative to conventional single-phase coolants in refrigeration systems. Nowadays, indirect cooling systems are spreading out due to regulations for the use of synthetic refrigerants and the possibilities that these systems provide for thermal energy storage. Jose et al. (2007) has given one advantage of using ice slurry that milk quality is improved by its quicker cooling rates.

Milk is approximately 32-38°C when it leaves the udder of cow. At this temperature, bacterial count doubles every 20 min, so milk needs to be cooled to 4°C as soon as possible, preferably within an hour of milking. As the milk has to be transported to longer distances from milking centre to collection centre, considerable time is involved in between for micro-organisms to grow. Chilling, therefore, is considered necessary to protect milk from spoilage soon after the process of milking. It is the most effective means of controlling the growth of microorganisms without affecting the physico-chemical properties and nutritive value of milk. It process does not kill microorganisms but only acts as a mean of checking the growth of microorganisms for some time. It is recommended to cool the milk as quickly as possible to 4°C, as per the Food Safety & Standard Act 2006.

The rate at which milk can be cooled depends upon the rate at which coolant can absorb heat from raw milk. Some materials absorb heat much more rapidly than others. Air absorbs heat very slowly, for example, if a can of warm milk is placed in a refrigerated room where the air temperature is at the freezing point, it will take 12 h to cool the milk to 10°C. On the contrary, water cools the milk over 20 times faster than air. Davies (2005) observed that the latent heat of fusion for 454 g of ice is equivalent to sensible heat of water to raise its temperature from 0°C to 80°C.When ice is present in the cooling tank, the heat from milk to the coolant is used up largely in melting of ice and thus, enhance the efficiency of the cooling system. Since, the milk must give up its heat to the surrounding ice, the larger the volume of ice and the lower its temperature, the faster the cooling process.

These outstanding features of the ice slurry are bringing about an increasing interest in this technology, which has been successfully employed in many patented designs of milk cooler by several inventors (William, 1889; Moses, 1923; Glenn, 1928; John, 1931; Vernor, 1939; Harry, 1942; Harnold, 1952; Russell, 1952; John, 1953; Westye, 1955). The applications of ice slurry can be grouped into direct applications and its use as a secondary fluid in indirect cooling systems. Most of the direct applications are related to the processing and preservation of food products such as fish and dairy, etc.

The purpose of the study was to ascertain the kind of phase changing material, its ratio to the product and the type of environmental conditions for achieving the desired cooling rate for milk as per the standards.

2 Materials and methods

2.1 PCM Selection

Since, the milk is produced countryside and used in urban areas. It needs transportation and chilling during the transit period. In developing countries like India, no method is currently applied for chilling of milk at farm level. This is because the present method of getting refrigeration effect is the use of compressor based system which needs much energy and is costly in initial investments. Therefore, it was given prime importance that the material selected should be easily available at the lowest possible cost. Several researchers as mentioned earlier have employed cold water and ice as cooling medium in their patented designs due to the fact that water is one of the phase changing material having desirable properties, and is safe to use and available everywhere. The choice of silica gel was made keeping in view its use in pharmaceuticals to preserve drugs and vaccines, therefore, is easily available in the local market.

2.2 Experimental setup

A stainless steel container of size 0.26×0.16×0.17 m was taken and 4 kg of product i.e. water/milk was kept in this container. Three different coolants to product ratios i.e. 1:2, 1:3 and 1:4 (by volume) of two selected phase changing material (ice and silica gel) were measured and packed in LDPE (Low Density Polyethylene) packages of size 0.20×0.15 m to optimize the amount of coolant to be used. The packages were kept overnight in refrigerator to convert its phase into solid. These LDPE packages of PCM were dipped fully in the product kept in stainless steel containers. The initial temperature of the milk and water was noted using mercury thermometer (ranges between -10°C to 100°C) before inserting the LDPE packages. The containers were covered with the aluminium foil and were kept in the insulated box as well as under control condition as is shown in Figure 1a, b. After immersing the packages in the container, the temperature was noted at the interval of 5 min for 1 h but afterwards the readings were taken at the interval of 15 min till the temperature became constant.

a b

Figure 1 Experimental set up (a) under insulated conditions (b) under ambient condition

The drop in temperature of milk and water was noted with respect to time in order to check the performance of the system. The faster the rate of cooling, more suitable is the coolant for the system. As thermal properties of both water and milk are similar so, trials were run taking water as product to be cooled to compare the performance of ice and silica gel so as to avoid the milk loss. After optimizing the operating conditions, type of PCM and its ratio, the experiment was run again, taking milk as product to be cooled.

2.3 Statistical analysis

Three replications of each experiment were made to minimize the experimental error. The data was analysed on the basis of coefficient of determination (R^2) values obtained from regression equation at 5% level of significance.

3 Results and discussion

Results for type of coolants used; ice pack and gel pack, environmental conditions; insulated and non-insulated, coolant to product ratios; 1:4, 1:3, 1:2 were analysed and discussed as below.

3.1 Type of coolant

The variation in temperature with respect to time for both water as well as milk using gel pack and ice pack as coolant under insulated condition has been shown in Figure 2. It has been observed that temperature dropped rapidly in initial stage, i.e. up to 12 min of cooling and later the change was gradual till the temperature became constant. However, among gel pack and ice pack, cooling effect of ice pack was found faster for both water as well as milk. The reason for such variation in cooling effect of both coolants might be due to higher latent heat of fusion for ice.

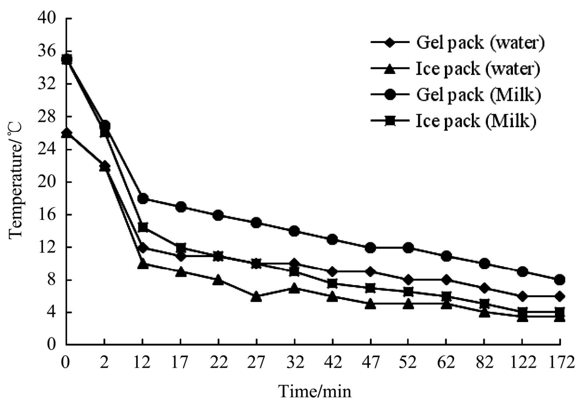

Figure 2 Product temperature variation for selected coolants under insulated condition

The logarithm equation with the coefficient of determination (R^2) values for temperature variation with time for ice pack and gel pack both in water and milk under insulated condition are shown in Table 1. R^2 value in case of ice pack is higher for both milk and water under both insulated and non-insulated conditions. However, ice pack in milk under insulated condition is showing the significant result (p<0.05).

Table 1 Regression equations and coefficients of determination for selected experimental conditions

Parameter	Regression equation	R^2- Value
Without insulation		
Ice pack in water	y = -5.511ln(x) + 24.559	0.90
Gel pack in water	y = -6.014ln(x) + 22.428	0.73
With insulation		
Ice pack in water	y = -7.115ln(x) + 23.874	0.89
Gel pack in water	y = -8.324ln(x) + 23.55	0.88
Ice pack in milk	y = -9.253ln(x) + 32.15	0.95^*
Gel pack in milk	y = -11.05ln(x) + 31.139	0.93
Coolant to product ratios with insulation		
1:2	y = -8.817ln(x) + 21.375	0.97^*
1:3	y = -8.756ln(x) + 21.232	0.93
1:4	y = -7.08ln(x) + 21.57	0.91

Note: *y represent temperature and x represent time, * represent value is significant at p<0.05.

3.2 Environmental condition

In order to observe the effect of insulation on cooling of water using ice pack, an experiment was conducted and results are shown in Figure 3.

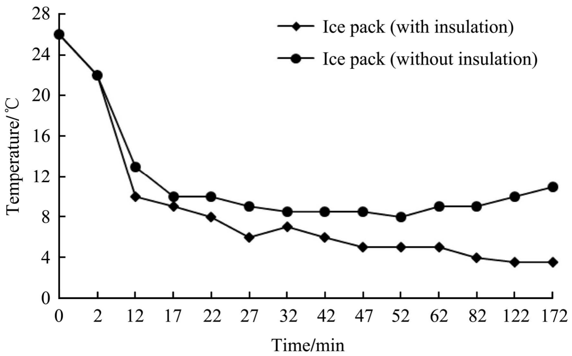

Figure 3 Effect of insulation on cooling rate of product for selected coolant

The perusal of figure shows that cooling under insulated condition yields better results. However, under non-insulated conditions, the drop in temperature was positive initially but after 52 min of cooling, the temperature drop became negative, i.e. temperature started to increase before attaining the desired temperature due to complete melting of ice. The relation between temperature drop and time for ice pack with and without insulation can be represented by regression equation as is shown in Table 1. It was noted that R^2 value for both ice pack and gel pack under insulated condition is greater than under non-insulated condition and under insulated condition, the ice pack in milk is showing significant result (p<0.05) for coolant to product ratio of 1:2.

3.3 Coolant to product ratios

Since in previous experiment, it was observed that ice pack resulted better cooling effect in comparison to silica gel pack thus, ice pack was taken to optimize the coolant to product ratio. Figure 4 shows the temperature variation with respect to time for different coolant to product (water) ratio under insulated condition.

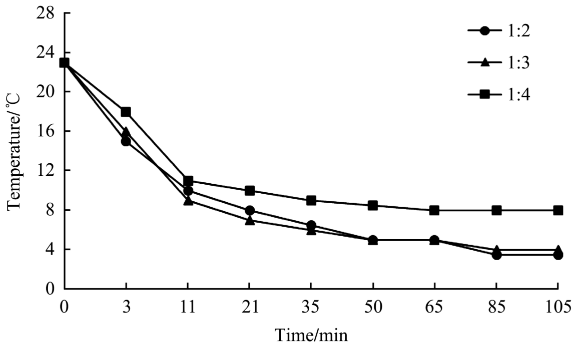

Figure 4 Temperature variation for selected ratios of coolant under insulated conditions

It showed that coolant to product ratio of 1:2 and 1:3 resulted almost similar cooling effect. So there is no benefit of using coolant to product ratio 1:2 over 1:3 in obtaining the same temperature because it can only lead to cost increment due to more usage of coolant for similar result. On the other hand, in case of 1:4, ice got melted before the liquid attained desired temperature. The relation between temperature variation and time for different coolant to product ratios under insulated condition can be represented with regression equation and is shown in Table 1. It can be clearly seen from the table that coolant to product ratio of 1:2 showed significant result (p<0.05) as compared to other two ratios.

4 Conclusion

The study showed that the cooling of milk can effectively be done by immersing the ice packs in milk by using ice to product ratio in range from 1:3 to 1:2 under insulated condition within the recommended time as per standards.

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