



Milk Cooling Prototype and its Economics

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Received: 01 Feb 2026; Received in revised form: 03 Mar 2026; Accepted: 13 Mar 2026; Available online: 21 Mar 2026

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Abstract— Milk is nearly complete food but as well as it is very perishable in nature, rapid preservation techniques are required to preserve its quality and to increase its spoilage time. Although, milk is nearly sterile when it comes out from the udder of a milch animal but when microbes get entry they deteriorate its quality. With the 23% contribution or 1st in milk production, India is not even in the top 10 in the export list of milk and milk product due to quality issues; so, there is need to preserve the quality of milk right from farm. In India 57% out of total milk production is produced by small farmers who have average herd size less than 3 milch animals so, there is need of small scale cooling system. The present study is focused for the small scale milk cooling system to maintain the cooling chain from farm to consumer. A vacuum chamber along with vacuum pump was used to for the cooling of milk. Milk cooled down from 36.3°C to 21.5°C just by using water as refrigerant, which may prevent milk spoilage up to 8 hours. The cooling cost is Rs 3.12 per litre of product.



Keywords— Dairy, Milk production, Vacuum chamber, Vacuum pump, Milk spoilage

I. INTRODUCTION

In recent month “International Dairy Federation World Dairy Summit 2022” was organised in India the last such summit was held in India nearly 50 years ago in 1974, when India’s milk production was 23 million tonnes which has now reached nearly 220 million tonnes, nearly 10 times increment. In these years India moved from milk deficient country to largest milk producing country and now India is contributing nearly 23% to world milk production and still the growth rate of India’s milk production is about 6% against 2% growth of world milk production.

Milk is almost sterile when it comes out from udder of milch animal (Uddin et al., 2011) but when microbes get entry into it, they lead to its deterioration because nearly neutral pH, high nutrient content, the ambient environment temperature and high water activity all are favourable condition for the rapid replication of microbes (Srairi et al., 2013). To suppress the growth of

microbes, the favourable condition are required to change; milk cooling is best for preservation.

Although some other systems are there, by taking the advantage of the antimicrobial compound, Lacto peroxidase system milk can be preserved for several hours, only lacto peroxides have no antibacterial effect but when it combined with hydrogen peroxide and oxidize thiocyanate the resulting compound have antibacterial effect. Lacto peroxides is present in milk and is sufficient for antibacterial action. Thiocyanate is also present in milk in 4-5 ppm which is not sufficient so, to adjust 15 ppm concentration, for required hydrogen peroxide granulated sodium carbonate peroxide is added to milk which produce 8-9 ppm hydrogen peroxide. If milk kept in dark ventilated place at 30 degree Celsius temperature lactoperoxidase (LP) system’s preservative effect lasts for 7-8 hour (Seifu, E. et al., 2005).

Milk may get spoiled due to the growth of fermentative bacteria during the storage at ambient temperature. The spoilage causing microbes for milk are

gram – positive spore forming bacteria (*Clostridium spp.*), gram – negative bacteria (*pseudomonas spp. Coliforms*) Lactic acid bacteria (*streptococcus*) (TeGiffel& Wells-Bennik, 2010). According to the climatic condition of India which provide favourable temperature for the growth of microbes, rapid cooling system is required for milk cooling to prevent milk spoilage.

Table 1 shows some refrigerants with their ozone depletion and global warming potential, so there is need of eco – friendly cooling system to reduce the global warming effect.

Table 1 Various refrigerants with the ozone depletion and global warming potential

| S.no | Refrigerant number | Chemical composition | ODP | GWP 100 YEAR |
|------|--------------------|---------------------------------|-----|--------------|
| 1 | R-11 | CCl ₃ F | 1 | 4750 |
| 2 | R-12 | CCl ₂ F ₂ | 1 | 10890 |
| 3 | R-13 | CClF ₃ | 1 | 14420 |
| 4 | R-23 | CHF ₃ | 0 | 14760 |

ODP- Ozone depletion potential, GWP- Global warming potential (Calm & Hourahan, 2007)

In India 57% out of total milk production is produced by small farmers who have average herd size less than 3 milch animals (Juniwal et al., 2022). In India “production of milk by masses” more than by “mass production” so, there is need of small scale cooling system. On the basis of these problems the present study is framed for small scale milk cooling system.

II. MATERIALS AND METHODS

Materials

A 500 mL stainless steel bottle wrapped with cotton and vacuum machine setup as shown in Fig. 1 was used. Thermometer and weighing balance was used for the measurement of temperature and weight respectively.



Fig. – 1 Cotton wrapped bottle inside vacuum machine

A vacuum chamber made up off stainless steel with accessories opening/closing valve and vacuum gauge and RTD (resistance temperature difference) thermometer for temperature measurement along with vacuum pump to create vacuum inside the chamber as shown in Fig. 2 and table – 2 shows the dimensions of the vacuum chamber and table – 3 shows the specifications of vacuum pump.



Fig. 2: - A - Vacuum chamber, B - Vacuum gauge, C - Valve, D - Display, E - Temperature sensor, F - Vacuum pump

Table – 2 Dimensions of vacuum chamber

| | | |
|--------|---------------|-------------|
| | Diameter (mm) | Height (mm) |
| Cavity | 420 | 520 |

Table – 3 Specifications of vacuum pump

| Sr. No. | Specification | Vacuum pump (flow tech) |
|---------|-------------------|-------------------------|
| 1 | Motor speed (rpm) | 1440 |
| 2 | Motor power (W) | 1HP |
| 3 | Frequency (Hz) | 50 |
| 4 | Oil capacity (ml) | 750 |

III. METHODOLOGY

Pre – trials for cooling under vacuum were taken by using cotton wrapped bottle and vacuum machine setup. 500 ml water filled in bottle (temperature measured using thermometer) and cotton was wrapped over the bottle. Water was sprayed over the cotton wrapped bottle and weighed before and after spraying water to measure the quantity of sprayed water, this was kept under vacuum using vacuum machine and again weighed to measure the quantity of water and final temperature of water was recorded to check the cooling effect.

Fig. 3 shows the arrangement of Can inside the vacuum chamber, the Can was filled with product and the space between the Can and vacuum chamber was filled with water as refrigerant. The RTD (temperature sensor)

was dipped inside the Can to measure the temperature of inner cavity product and the vacuum chamber closed, and vacuum was created inside the vacuum chamber which help to reduce the boiling point of water. When water evaporate by taking the latent heat of evaporation and convert from liquid form to vapour and give cooling effect.



Fig. 3 The Can inside vacuum chamber

IV. RESULTS AND DISCUSSION

Pre – trial on cotton covered bottle in vacuum packaging machine

The results of this experiment are shown in table- 4; the cumulative temperature drop and quantity of water evaporated was 14°C and 27.16 g respectively in 1680 sec.

Table 4: Temperature profile and water evaporation of cotton covered bottle

| Duration (second) | Water in inner cavity(mL) | Water on outersurface (absorbed in cotton) evaporation | Cumulative water evaporation (g) | Temperature (mean value) of water in inner cavity (°C)± SE | Cumulative decrease in temperature in inner Cavity (°C) |
|-------------------|---------------------------|--|----------------------------------|--|---|
| 0 | 500 | 50 ± 0.00 | 0 | 39 ± 0.577 | 0 |
| 240 | 500 | 37.22 ± 0.295 | 12.78 | 34 ± 0.00 | 5 |
| 480 | 500 | 34.13 ± 0.066 | 15.87 | 32 ± 0.33 | 7 |
| 720 | 500 | 31.22 ± 0.070 | 18.78 | 30 ± 0.33 | 9 |
| 960 | 500 | 28.34 ± 0.036 | 21.66 | 28 ± 0.577 | 11 |
| 1200 | 500 | 25.94 ± 0.176 | 24.06 | 27 ± 0.577 | 12 |
| 1440 | 500 | 23.92 ± 0.179 | 26.08 | 26 ± 0.577 | 13 |
| 1680 | 500 | 22.84 ± 0.242 | 27.16 | 25 ± 0.577 | 14 |

N=3, Values are average ± SE (standard error)

Fig. 4 shows the temperature profile of water in inner cavity of SS bottle covered with cotton and Fig. 5 shows the evaporation of quantity of water from outer surface of

bottle. As shown in Fig. 4 and 5 initially the cooling effect was high as the quantity of water evaporated was also high.

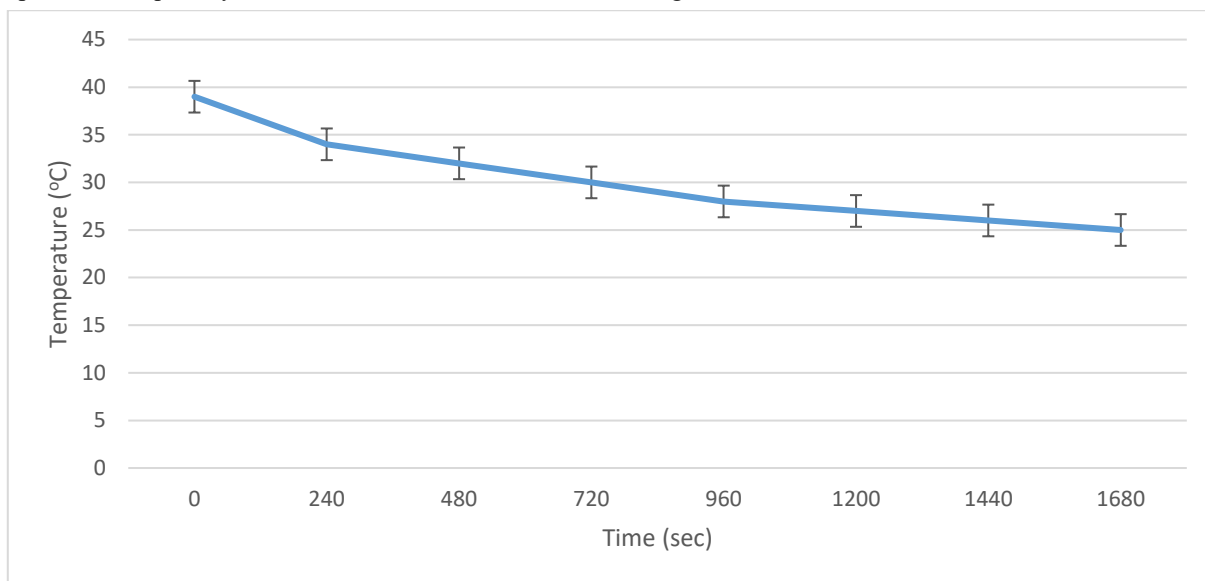


Fig. 4: Temperature profile of water in inner cavity cotton covered bottle

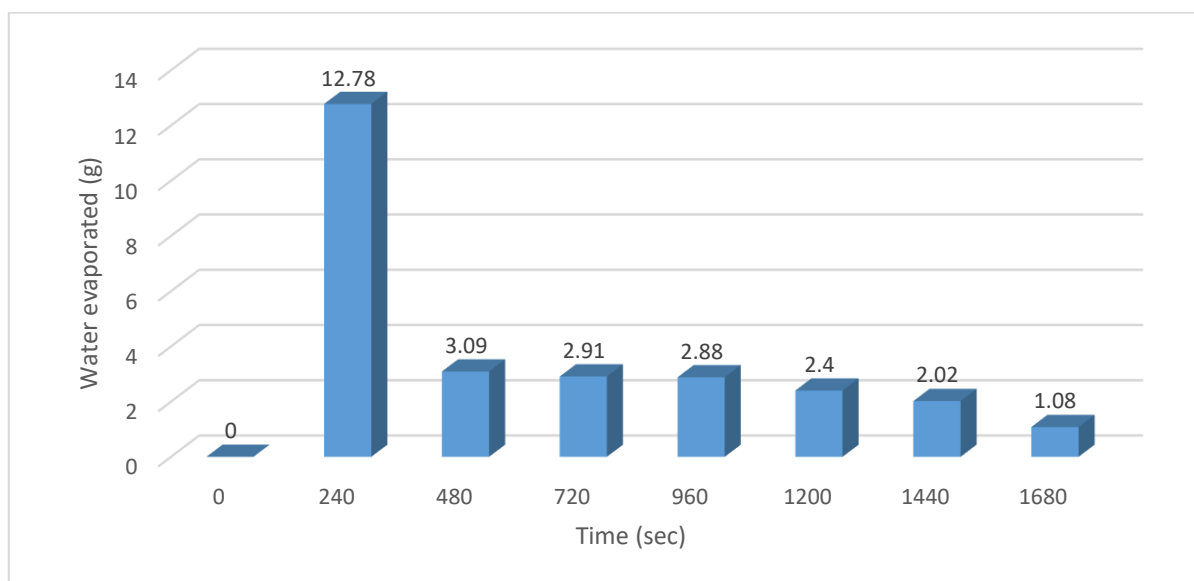


Fig. 5: Quantity of water evaporated from outer surface of cotton covered bottle

It may be concluded that there is a direct relation between the rate of evaporation of water and cooling effect in the inner cavity of the bottle

Cooling effect in inner cavity Can in vacuum chamber

Methodology provided above, 5000 mL water was filled in vacuum chamber and 10000 mL product

filled in 40 litre (capacity) Can. The filled Can was directly kept inside the vacuum chamber. Table 5 and table 6 shows the temperature profile of inner cavity Can in vacuum chamber at 710 and 730 mmHg vacuum respectively. The cumulative temperature drop in inner cavity product at 710 mmHg was 7.4°C, at 730 mmHg 9.6°C after 5400 and 9000 sec respectively.

Table 5: Temperature profile of inner cavity water (Can) in vacuum chamber at 710 mmHg vacuum

| Duration (sec) | Vacuum in outer cavity (mmHg) | Temperature in inner cavity (°C) (5000 mL and 10000 mL water in vacuum chamber and inner cavity (can) respectively) ± SE | Cumulative decrease in temperature in inner cavity(°C) |
|----------------|-------------------------------|--|--|
| 0 | 710 | 36.3 ± 0.212 | 0 |
| 900 | 710 | 33.6±0.212 | 2.7 |
| 1800 | 710 | 32.5±0.212 | 3.8 |
| 2700 | 710 | 31.6 ± 0.212 | 4.7 |
| 3600 | 710 | 30.6±0.212 | 5.7 |
| 4500 | 710 | 29.6 ± 0.212 | 6.7 |
| 5400 | 710 | 28.9 ± 0.212 | 7.4 |

N=3, Values are average ± SE(standard error)

Fig. 6 shows the cooling effect in inner cavity water of Can placed in the vacuum chamber at the vacuum of 710 mmHg and Fig. 7 shows the temperature profile of water at 730 mmHg vacuum.

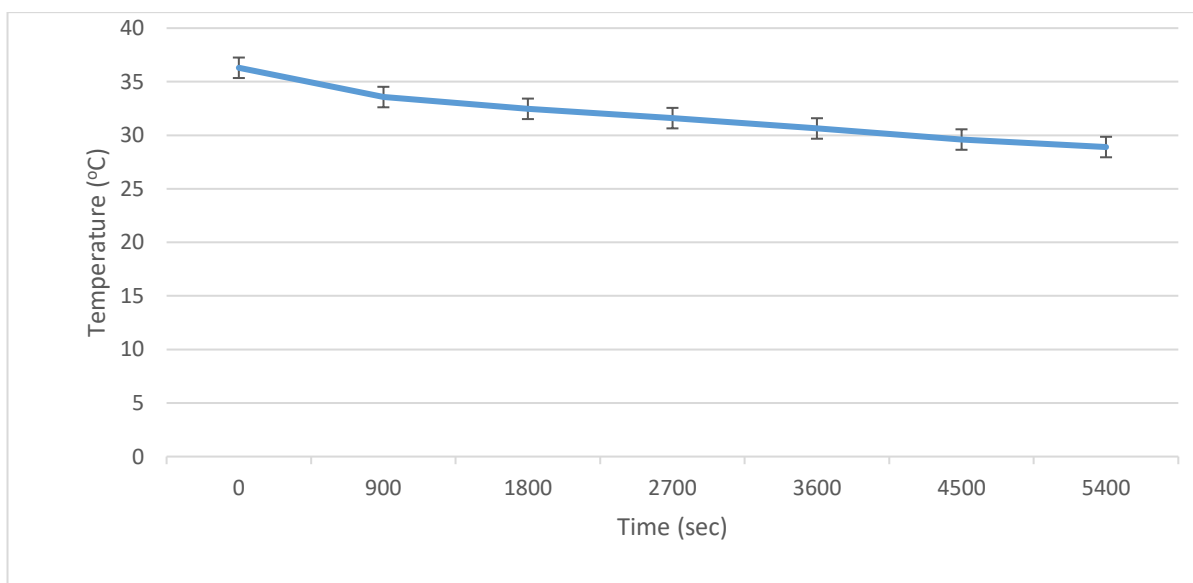


Fig. 6: Temperature profile of inner cavity water (Can) in vacuum chamber at vacuum 710 mmHg

Table 6: Temperature profile of water in Can placed in vacuum chamber at 730 mmHg vacuum

| Duration(sec) | Vacuum in outer cavity (mmHg) | Temperature in inner cavity (°C) (5000mL and 10000 mL water in vacuum chamber and inner cavity (can) respectively) ± SE | Cumulative decrease in temperature in inner cavity(°C) |
|---------------|-------------------------------|---|--|
| 0 | 730 | 31.1 ± 0.293 | 0 |
| 900 | 730 | 28.6±0.293 | 2.5 |
| 1800 | 730 | 27.1±0.293 | 4.0 |

| | | | |
|------|-----|--------------|-----|
| 2700 | 730 | 26.1 ± 0.293 | 5.0 |
| 3600 | 730 | 25.1±0.293 | 6 |
| 4500 | 730 | 24.3 ± 0.293 | 6.8 |
| 5400 | 730 | 23.6 ± 0.293 | 7.5 |
| 6300 | 730 | 23.1 ± 0.293 | 8 |
| 7200 | 730 | 22.6 ±0.293 | 8.5 |
| 8100 | 730 | 22.1 ± 0.293 | 9.0 |
| 9000 | 730 | 21.5 ± 0.293 | 9.6 |

N=3, Values are average ± SE (standard error)

Fig.7 shows the cooling effect in water in Can placed in the vacuum chamber at the vacuum of 730 mmHg.

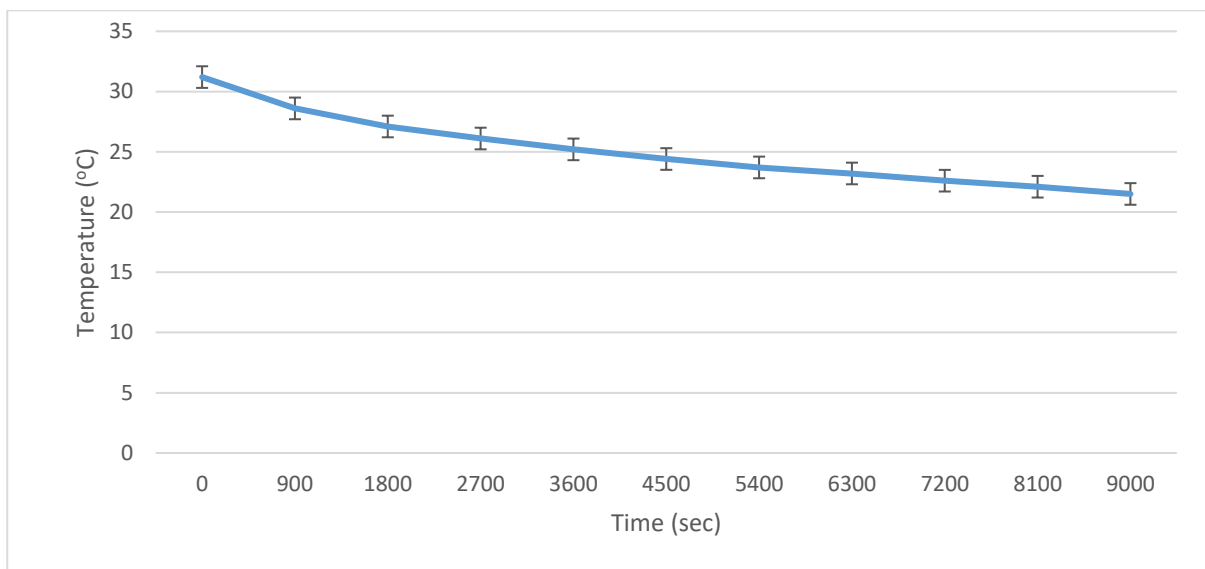


Fig. 7: Temperature profile of water in Can placed in vacuum chamber at vacuum 730 mmHg

The temperature drop in inner cavity water was very low. Fig. 8 shows the water vapour condensed on the surface of lid. The vapour generation in vacuum chamber was more as compare to vapour removal

from the chamber, and vapour started to exert vapour pressure on evaporation and reduce the vapour formation so the cooling rate was less even at higher vacuum level.



Fig. 8: Condensed vapour inside the chamber

The mass flow rate of vapour through the vacuum pump depends on the density of vapour and speed of vacuum pump (Wang and Sun, 2001).

$$M_v = S_p \times \rho_v$$

Where

M_v = Mass flow through vacuum chamber S_p = Speed of vacuum pump (rpm)

ρ_v = Density of vapour

One kg water vapour require 2000 m³ volume (Barger, 1961) so, at that much volume vapour do not exert any vapour pressure and not affect water evaporation rate from the free surface of water.

ECONOMICS OF DEVELOPED PROTOTYPE

Cost analysis of milk cooling system for future scale

Table 7: Energy consumption by vacuum pump

| I(Current) | V (voltage) | Cosφ(power factor)= real power/apparent power | AC supply Power = V×I×Cosφ Watt | Power= watt= Joule /sec | Total energy consumption = W×Time(sec) joule |
|------------|-------------|---|---------------------------------------|----------------------------------|---|
| 3A | 248V | 248×3/746 = 0.997 | 3×248×0.997= 741.76 | 741.76 J/sec | 741.76×3000= 2225280joule |

up of the prototype (expected)

The milk cooling cost of the developed prototype, 10 litre milk cool down from 36.3°C to 21.5°C by running vacuum pump for 4h (14400 sec). For milk cooling purpose energy (electricity) input only to run the vacuum pump, so cost of electricity consumed by vacuum pump. Table 7 shows the energy consumption by vacuum pump.

1unit electricity = 1KWh = 1000×3600 joule

Electricity consumption by vacuum pump = 2225280 joule (from table 7)

Electric unit consumption by vacuum pump = 2225280/3600000 = 0.61813 unit (in 50min.) Electricity consumption in 240 min. = (0.61813 ÷ 50) × 240 = 2.96 unit

Table 8 and 9 shows the fixed and variable cost for milk cooling respectively.

Table 8: Fixed cost for 10 litre set up (assumption)

| s.no. | Item | Cost | Per hour working cost | Total time per batch | Total cost Rs |
|-------|--|--------|--|-----------------------------------|---------------|
| 1 | Equipment cost | 20,000 | | | |
| 2 | Depreciation on equipment @10% /annum | 2000 | Depreciation on equipment@10% /hour= 0.2283 | Total working hour per batch = 4h | 0.9132 |
| 3 | Interest on capital investment @12% /annum | 2400 | Interest on capital investment@12% /Hour =0.2739 | Total working hour per batch = 4h | 1.0956 |
| 4 | Cost of vacuum pump | 40,000 | | | |
| 5 | Depreciation on equipment @10% /annum | 4000 | Depreciation on equipment@10% /hour=0.4566 | Total working hour per batch = 4h | 1.8264 |
| 6 | Interest on capital investment @12% /annum | 4800 | Interest on capital investment@12% /Hour= 0.5479 | Total working hour per batch = 4h | 2.1916 |
| | Total fixed cost | | | | 6.02 |

Table 9: Variable cost for 20 litre milk cooling

| s.no | Item | Cost | Per unit charge | Total cost (Rs) |
|------|--|-----------------------------|--|-----------------|
| 1 | Electricity cost | Total consumed =2.96unit | Per unit price = 5.76 | 17.049 |
| 2 | Cleaning cost @1% of Production cost | | | 0.38 |
| 3 | Maintenance cost @2% of equipment cost | 43000 @ 2%/annum | Maintenance Cost per hour= 0.1369 | 0.55 |
| 4 | Labour cost | 10 min. | Rs –350 Unskilled labour per day 8h | 7.29 |
| | TotalVariablecost | - | - | 25.269 |

Total cost = fixed cost + variable cost = 6.02 +25.269
= 31.289

Per litre milk cooling cost(10 litre product from 36.3°C
to 21.5°C) = 31.289/10= Rs3.12

V. CONCLUSION

The temperature of product is reduced from 36.3 °C to 21.5 °C in 14400 sec. In this cooling system water was used as refrigerant so, this cooling system will help to control the effect of global warming and ozone depletion. The cooling of milk right from farm will help to preserve the quality of milk by inhibiting the growth of microbes.

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