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CONCEPTUAL DESIGN APPROACH OF FARM MILK CHILLER

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ABSTRACT
India is the largest milk producer as well as consumer of milk and milk products play significant role in Indian diet and are the most acceptable source of animal protein for large vegetarian segment of Indian population. Effective on-farm cooling of milk and maintenance of low temperature while transporting it from milking centre to collection centre is very important to ensure the quality of milk. To design an effective cooling system for on farm cooling of milk, there is a need to focus on some parameters like cooling rate, hygiene conditions, ergonomic features, etc. The present paper is an attempt to discuss the approach for designing a workable, easy to handle, low cost and sturdy farm milk chiller for maintaining the milk quality and cool chain during the initial stage of milk handling.

INTRODUCTION
India accounts for most dairy cows and buffaloes and over 90% of all Asian milk production. India is the world's largest milk producer, accounting for over 16 % of the total global dairy output (Anonymous, 2016). The annual average growth rate in milk production in India stood at 4.5 % per annum during the last decade with the milk production rising from 22 million tonnes in 1970 to 138 million tonnes in 2013-14. Per capita availability of milk has increased from 112 gm/day in 1970 to 302 gm/day in 2013-14 (Anonymous, 2016), which also meets the minimum nutritional requirement of 280gm/day as recommended by Indian Council of Medical Research (ICMR). India is not only the leading milk producer but also the world’s largest consumer of milk.

Several factors have contributed to increased milk production. First, milk and dairy products have cultural significance in the Indian diet. Dairy products are a major source of cheap and nutritious food to millions of people in India and it is the only acceptable source of animal protein for large vegetarian segment of Indian population. Second, the demand for milk and dairy products is income-responsive, and growth in per capita income is expected to increase demand for milk and milk products (Sharma et al., 2003).

MODES OF MILK TRANSPORTATION
In most of the countries, milk is transported to milk processing plant using different modes of transportation such as human, animal, non-motorised vehicles and motorised vehicles via road, rail, can, tanker, etc. Under unorganised dairy sector, small scale dairy farmer with 15-25 kg per day milk production can transport milk manually, cans or any other domestic utensils for a short distance ranging 3-8 km. On the other hand, draught animals like ponies, horses, donkeys, etc. are used to transport up to 80 kg milk for a distance of 6-10 km. Although, these are the cheapest methods of milk transportation, the large quantity of milk cannot be handled at a time. These are time consuming so are less reliable. While medium scale dairy farmer with milk production 40-400 kg, uses non- motorised mode of milk transportation like bicycles, cycle rickshaw, tongas, bullock carts, etc. for comparatively longer distance. The best possible way which is prevalent in organised sector for large quantity of milk transportation is by motorised vehicles through cans or tankers. The advantages of this mode includes better temperature control, less risk of contamination, low cost, time and labour saving. Of the milk produced, 40 percent is used or consumed on-farm whereas 60 percent is sold. Industry sources report that 70% of milk sold goes through the unorganized sector in cans in open markets, and only 30% through the organized sector (16 percent by cooperatives and 14 percent by large private processors) (Khan et al., 2013). The consumers are trending towards branded milk products for quality and safety concerns. Immediate cooling, thus,

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is an important factor in deciding the quality of milk and its acceptance and rejection at plant. According to Code of Hygienic Practice for Milk and Milk Products (2004), it is recommended that further processing of incoming raw milk is not allowed if it is not cooled to minimize any increase of the microbial load of the milk.

Importance of milk chilling
In India, there are 14 major milk producing states: Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal which account for over 90 percent of total milk production. The annual average environmental temperature in these areas remains nearly 35^{0}C which is conducive for micro-organisms to grow to turn the milk sour. Fig. 1 shows, the bacterial growth in milk held at ambient temperature.

During the initial phase i.e. lag phase of bacterial growth, the multiplication of bacteria is slow and depends primarily on the initial contamination and, to a lesser extent, on composition of the milk. This is further followed by the log phase during which, the bacterial population rises up quickly and results into an irremediable deterioration in milk quality. The duration of lag phase varies from 10-15 hours to 2-3 hours for very clean milk (1000 bacteria/ml) to milk containing several thousand bacteria/ml, respectively held under same condition. Therefore, precautions must be taken during the lag phase (i.e. 2-3 hours after milking) in order to preserve milk quality. Bacterial growth being a function of temperature, the simplest mean to check it is to cool the milk to 4^{0}C immediately.

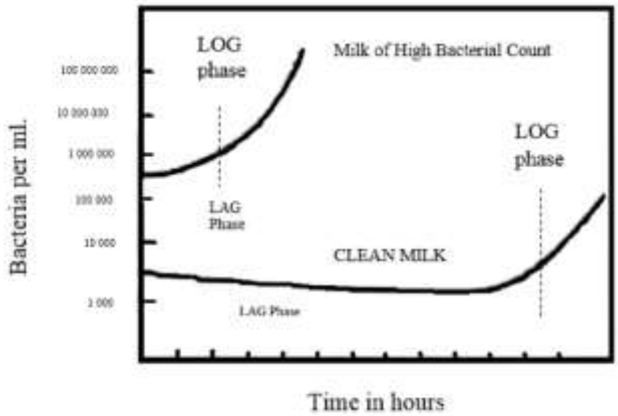

Fig. 1: Growth of bacterial population in milk held at room temperature (Source: Anquez and Tiersonnier, 1962)

The importance of cooling milk on the farm and of holding it at a low temperature while transporting it to the receiving station or milk plant is another serious developmental issue. To combat this problem of refrigeration at farm level, many researchers (William, 1889; Moses, 1923; Glenn, 1928; John, 1931; Vernor, 1939; Harry, 1942; Harnold, 1952; Russell, 1952; John, 1953; Westye, 1955) have made efforts to develop such milk cooling devices (US patented) which were based on either direct or indirect cooling. However, such designs have proved to be impractical, unsatisfactory or uneconomical, for various reasons. An attempt has been made to conceptualise the design of farm milk chiller in respect of mechanical, refrigeration, hygiene and ergonomics parameters by considering the drawbacks of existing designs. This paper discusses the possible approach of designing a workable, easy to handle, low cost and sturdy farm milk chiller.

DESIGNING APPROACH

In the current method of transportation of milk, raw milk is collected in the can and loaded directly on to the milk collecting vehicle, is transported to chilling centre without any primary chilling at root level and cooled to 4°C within 2 hours. Handling and loading methods of milk cans to the vehicle are also very crude. Hence, there is a necessity for primary chilling as well as proper transportation. In course of the study of designing approach of milk chiller, some patented designs by several researchers were reviewed. It was noted that there were certain drawbacks in these designs which made them less attractive to dairy farmers. These drawbacks are listed below:
Drawbacks in existing technologies

1. Heavy weight of the cans when filled with milk. These cans have to be lifted into and out of the coolers, by the employees on the farm.

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2. Quantity of milk requiring cooling vary from time to time and from place to place but the designed coolers are of specific capacity which results in the consumption of more power than necessary at all other times.
3. Refrigeration units employs a method of cooling in which the refrigerated water is sprayed over the milk cans and the water recirculated and passed over a suitable refrigeration coil prior to being sprayed over the cans again. It requires more time to effect a thorough and satisfactory cooling of the milk in the can.
4. In small dairies, the milk is ordinarily cooled by placing the milk cans in large tanks of ice water. This method of cooling usually requires more time during which the bacteria in the milk are allowed to multiply considerably.
5. In large dairies, cooling process is usually performed in expensive aerators whereby the milk is passed over cold pipes containing a cooling medium. Such devices are too expensive and complicated for practical use in small dairies.
6. In the milk coolers it is customary to provide a vat having a suitable cooling liquid therein and to provide suitable apparatus for refrigerating the cooling liquid. No means are employed for either circulating the cooling liquid or the milk within the cans. Consequently, considerable time is required to cool the milk which when placed in the cooler is relatively warm.
7. In one type, the can is retained in a substantially submerged condition in the cooling liquid against the buoyant effect of the liquid and consequently difficulty is encountered in retaining a can only partially filled with milk in a submerged condition.

MECHANICAL DESIGN

VOLUME OF THE PRODUCT

Most of the milk in developing countries is produced by marginal and small farmers rearing about less than 5 animals i.e. average 50-60 kg/day. The farm milk tank shall be designated by its rated capacity. Actual capacity is determined with the tank filled to a level of 60 mm below the top edge of the inner vessel. The tanks should be designed to the rated capacities of 500, 1000, 2000 litres for large dairy farms.

SHAPE OF THE TANK

The tank shall be so designed that all surfaces in contact with milk are readily accessible either in their position or after dismantling so as to permit thorough cleaning. In most of the designs, cylindrical shaped tank is used as it is easily cleanable, has less sharp edges. The tank should avoid the cracked parts and sharp edges as they are sensitive to accumulation of microorganisms (Akam et al., 1989).

STRENGTH OF EQUIPMENT

The surfaces of all component parts which come into contact with milk, shall be made of stainless steel AISI 304 grade. Physical dents and abrasion on surface may change the volume and increase its vulnerability to outside surface corrosion. Smooth surfaces not only promote good cleansibility but also reduce the risk of corrosion. All other parts surfaces of which do not come into contact with the milk, shall be made of a corrosion-resistant material.

LID DESIGN

The lid should be designed in such a way that it seal the container hermetically and restricts the entry of microbes from outside into the milk during cooling process. They should be made of food-grade materials, which are capable of being cleaned and sanitised properly.

REFRIGERATION DESIGN

COOLING RATE

Time and temperature conditions during storage and distribution have an important influence on the concentration of any contaminating pathogens. It is recommended to cool the milk as quickly as possible to 4°C, preferably within an hour of milking (Sharma, et al., 2014). If the milk is cooled to 4 ˚C within a period of 2-3 hours after milking, it maintains nearly its original quality and remains good for processing and consumption. Tanks designed for cooling and storage shall have refrigerating equipment of capacity sufficient to perform a) Cool 100 percent of nominal tank capacity from 38°C to 4°C b) Eliminate all stray heat gains; and c) Eliminate heat input from wash water.

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COOLANT SELECTION

The rate at which milk can be cooled depends upon the rate at which coolant can absorb heat from raw milk. The most common storage media for cooling are water, ice due to high latent heat of ice crystals, easy availability and low cost. The high heat transportation capacity of ice slurry and its low operating temperatures make it an excellent coolant in refrigeration systems. It has been successfully employed in many patented designs of milk cooler by several inventors (William, 1889; Moses, 1923; Glenn, 1928; John, 1931; Vernon, 1939; Harry, 1942).

COOLANT TO PRODUCT POSITIONING

Coolant should not be in direct contact with product as it becomes the major source of milk contamination. It will deteriorate the quality of raw milk and will lower its shelf life even when the milk is cooled to standard temperature. The growth of psychrotrophic organisms such as *L. monocytogenes* and *Yersinia enterocolitica* can still occur at refrigeration temperatures if organisms are present in the milk. Other pathogenic microorganisms, if present, will also grow if the temperature increases by only a few degrees, i.e. *E. coli* and *Salmonella spp.* may grow at temperatures between 7 - 8°C (Roberts et al., 1996).

INSULATION

The sides, ends and bottom of the tanks shall be insulated to reduce stray heat gains. The amount of insulation applied shall be such that the rise in the mean temperature of the content of a full tank initially at 4°C over a period of 8 hours in an ambient temperature of 43°C shall not exceed 2°C (Anonymous, 1996). The insulating medium employed shall be non-hygroscopic, non-settling and shall not be liable to displacement during transit or service. An effective vapour barrier shall seal the external surfaces of the insulating medium to prevent the ingress of moisture.

REFRIGERATION LOAD

Refrigeration level should be such that it runs on minimum required load. The rate at which heat must be removed from a refrigerated space in order to maintain a desired temperature is known as refrigeration load. It is dependent on several factors, including the volume of the space being cooled and the quantity and base temperature of product inside. Insulation also affects the refrigeration load. Without insulation, external heat will act on the space inside, attempting to reach equilibrium. Refrigeration load is often calculated to decide the amount of coolant needed for a required amount of product. Climate will play a role as well because humidity and air movement can affect temperature. Therefore, it is important to select the extreme conditions that can be encountered during refrigeration to calculate cooling capacity required. The factors which should be considered while calculating total refrigeration load are discussed below:

(a) Internal heat load: It is referred to as product heat that remains within the raw milk and can be calculated using equation 1. The amount of heat to be removed to cool raw milk to prescribe limits depends upon:
   i. Initial and final temperature of milk at time of loading and unloading, respectively
   ii. Quantity of the milk to be cooled

   $$Q = m\, C_p\, \Delta T \qquad (1)$$

   Where Q = Heat to be removed (kJ)
   m = Mass of milk to be cooled (kg)
   C_p = Specific heat of milk (i.e. 3.77 kJ/kg-°C)
   ΔT = Temperature difference (°C)

(b) External load: The external heat includes the heat of conduction, air infiltration and heat of radiations. The amount of heat transfer through conduction is a function of surface area where heat conduction occurs, the type and thickness of insulation and the temperature difference between inside and outside of the cooling walls. Infiltration is a source of heat gain which includes heat transfer through small holes, cracks, damaged surface and broken lid seals (absent in this case). Radiation also increases the refrigeration load and it can be minimised with the use of highly polished steel, aluminium plates or reflective plates on the outside surface.

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(c) Total refrigeration load: The total cooling capacity of the refrigeration system should be equal to sum of internal and external loads multiplied by safety factor (should be greater than unity). However, the actual calculation of cooling capacity is more complex since other factors have to be considered in the design of cooling system.

The refrigeration load/ capacity is expressed in terms of tons of refrigeration (TR). It is defined as the refrigerating effect produced by melting of one ton of ice from and at 0 °C in 24 h. In SI units, 1 TR is equal to 3516.8W or 211 kJ/min.

HYGIENE DESIGN

On-farm cooling and hygiene practices are critical, with any failure adversely impacting the microbial load in raw milk. Correct sanitising procedures for effective cold chain management practices for the raw milk are important steps for minimising cross contamination and growth of any microorganism present in the raw milk.

Contamination of milk via the milking equipment occurs when microorganisms and milk residues adhered to surfaces of milking equipment are not cleaned completely during cleaning. Visually clean surfaces should not contribute more than 1000 bacteria/ml of milk. However, surfaces ineffectively cleaned and sterilized or plant containing old milk residues will elevate the bulk milk count by at least 10,000/ml of bacteria (F. Harding, 1995). During the gap between two milkings, the concentration of adhered microorganisms may increase due to growth. During milking adhered microorganisms are released into passing milk and increase the microbial contamination. The tank must be cleaned and sanitized at least once in every 24 hours. All milk contact surfaces must be exposed to the sanitizing solution. Chlorine (200ppm) is an example of commonly used sanitizing agent. Sanitizing must be done immediately before loading to minimize corrosion and maximize effectiveness. The tank should be sterilized by hot water, steam or by hypochlorite sterilization. In addition, never spray cold water into a tank immediately after the washing to prevent collapse. The tank should avoid the cracked parts and sharp edges as they are sensitive to accumulation of microorganisms.

ERGONOMICS DESIGN

1. The system should be designed keeping ergonomic in mind and also reducing the effort and time for loading and unloading the milk cans into the chiller.
2. The permanent outer fitting or any other moving parts should be covered with casings to ensure the safety of human labour.

To reduce strain on worker's hand and arms, the head of system should be designed with its raised rim and wide grooves so that there is plenty of room to get a good firm grip

REFERENCES

1. Akam, FD., Dodd, FH and Quick, AJ. Milking, Milk Production Hygiene and Udder Health, Report No. 78, Food and Agriculture Organization of the United Nation, Rome; 1989, 56–95.
2. Anonymous, Indian Standard Specification for Farm Milk Cooling Tanks 1996. https://law.resource.org /pub/in/bis /S06/is.3661.1966.pdf; 1996 (Accessed on: Aug 14, 2014).
3. Anonymous, Indian Dairyman: The spirit of the dairy industry. 43rd DIC special, March 2015, 2016, 37. (Cited on: Jan 28, 2016)
4. Anonymous, National Dairy Development Board. http://www.nddb.org/sites/ default/files/pdfs/nddb-annual-report-2013-2014.pdf; 2016. (Accessed on: Jan 28, 2016).
5. Anquez, M and Tiersonnier, B. Milk Collection centre. WHO/FAO- in milk hygiene;1962, 545-56.
6. Glenn, MO. Milk can cooler. United States Patent No. 1664702; 1928.
7. Harding, F. Milk Quality. Blackie Academic & Professional Publications, London; 1995, 310.
8. Harry, CK. Portable milk cooler. United States Patent No. 2285520;1942.
9. John, AB. Milk cooler. United States Patent No. 1838610;1931.
10. John, RB. Milk cooler. United States Patent No. 2659579;1953.
11. Khan, N., Ganie, AA., Sewant, S. and Suman, M. Strategies to combat cold stress. Livestock Future. **4(4),** 2013**,** 7-8.
12. Moses, MC. Rapid milk cooler. United States Patent No. 1471449; 1923.
13. Roberts, TA., Baird-Parker, AC. And Tompkin, RB. Microorganisms in foods 5: Microbiological specifications of food pathogens. First ed, Blackie Academic & Professional, London, UK; 1996, 217-64.
14. Russell, CS. Milk cooler. United States Patent No. 2618127; 1952.

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15. Sharma, VP., Staal, S., Delgado, C. and Singh, RV. Policy, Technical, and Environmental Determinants and Implications of the Scaling-Up of Milk Production in India" Annex III, Research Report of IFPRI-FAO Livestock Industrialization Project: Phase II. Washington, D.C.: International Food Policy Research Institute; 2003.
16. Sharma, A., Gupta, S. and Kaur, K. Comparative study on phase changing material for refrigeration effect for milk chilling, Agric Eng Int: CIGR Journal, **16(3)**, 2014, 189-193
17. Vernon, WH. Milk cooler. United States Patent No. 2181553; 1939.
18. Westye, FB. Milk cooler. United States Patent No. 2700281; 1955.
19. William, WM. Milk cooler. United States Patent No. 414561; 1889.