DESIGN OF MOBILE RAW MILK CHILLING UNIT FOR RURAL AREAS

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Abstract

Transportation of raw milk from village to the dairy requires lot of care, as there is no chilling unit at the village collecting centre. Freshly collected raw milk at village co-operative societies is transported to chilling unit and the route is specified by the milk federation. In such a chilling unit, milk collected from many such routes is chilled and then transported to secondary processing unit once in a day. To maintain quality, the milk has to be chilled at village co-operative society level. Since, the quantity of milk collected is less (40 – 200 litre), chilling does not take place at this level. Bulk milk chillers are not suitable for this purpose. Currently, raw milk transport method is also not hygienic and loading-unloading methods are very crude without ergonomic consideration. A better solution for this problem is to transport raw milk stored in a refrigeration system, which has a proper layout, storage facility for milk cans, and handling equipment which will reduce the effort and time required to load and unload the milk cans.

Literature review on transport refrigeration of various food products was carried out by referring to books, journals, websites and refrigeration unit catalogues. Information regarding the present method of milk collection, primary chilling, transportation method of raw milk and documentation process was obtained from the Dairy Co-operative Societies. Information was also gathered by surveying the collection centres. Requirements to preserve the quality of the milk as well as information on duration of collection and transportation were collected. Data regarding the current trends of transport refrigeration were also collected. Heat loads were calculated as per the requirements. Based on the collected data, Product Design Specification (PDS) and Quality Function Deployment (QFD) were generated. Various concepts of the vehicle were sketched and a 2D layout was designed using AUTOCAD software. A final concept was selected and 3D model was created using ALIAS and CATIA geometric modeling software. A mock up model was built based on the final concept.

Heat loads obtained from calculations for route "G" and route "B" were 11125W and 9974W respectively. Weight calculations, cost estimation for the project and chilling cost were carried out. After chilling, the total price per liter of milk was approximately INR 28.70. This is a feasible alternative for good quality raw milk transportation. Chilling plant can be completely eliminated as mobile chillers are used for transportation of the raw milk.

Key Words: Dairy Co-operative Societies, Raw Milk, Chilling Unit, Heat Load, Ergonomic Design

Nomenclature

A	Area (m^2)
C_P	Specific heat capacity (kJ/kg°C)
K	Thermal Conductivity ($W/m\,K$)
Q_T	Transmission load (W)
Q_P	Product load (W)
Q_{inf}	Infiltration load (W)
T	Température (K)
U	Overall heat transfer (W/m^2K)
V	Volume (m^3)
h	Convective heat transfer coefficient (W/m^2K)
m_{air}	Mass of air (kg)
t	Temperature (^oC)
v	Specific volume (m^3/kg)

Abbreviations

ATP	Atmospheric Temperature and Pressure
BIS	Bureau of Indian Standards
CAGR	Compound Annual Growth Rate
DCS	Dairy Co-operative Societies
GRP	Glass Reinforced Plastic
GI	Galvanized Iron
ISSDA	Indian Stainless Steel Development Association
MACS	Mutually Aided Co-operative Societies
NDDB	National Dairy Development Board
PUF	Poly Urethane Foam
PDS	Product Design Specification
QFD	Quality Function Deployment
SS	Stainless Steel

1. INTRODUCTION

Dairy sector in India plays an important role in the country's socio-economic development and contributes to the very important segment of rural economy. Dairying has become an important secondary source of income for millions of rural families. It not only plays an important role in providing employment and income-generating opportunities next to agriculture, but also ensures supply of quality milk and milk products to both urban and rural areas. With the country's increasing demand for milk and milk products, the dairy industry is also growing rapidly. According to "Indian Dairy Industry Analysis", India is the world's largest milk producer, accounting for around 17% of the global milk production [1]. India ranks first in the world in milk production. The milk production went up from 17 million tonnes in 1950-51 to 121.84 million tonnes in 2010-11. The per capita availability of milk has also increased from 112 gms. per day in 1968-69 to 281gms. in 2010-11. The world average per capita availability was 284 gms. per day in 2009-10 compared to 273 gms. per day for India [1]. Consumption of dairy products has been growing exponentially in the country. Indian government is taking several initiatives and running programmes such as National Dairy Plan and Intensive Dairy Development Program to meet the growing demand for milk in the country [2].

More than 10 million dairy farmers are included in 96,000 local dairy cooperatives, who sell their products to 170 milk producers. The cooperative unions are supported by 15 state cooperative milk marketing federations [3]. Uttar Pradesh, Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu are the milk surplus states in India.

Dairy Cooperative Management is one of the strategies applied by Indian Government towards the success of the dairy industry [4]. These cooperatives help to collect, store and market milk safely.

Karnataka Milk Federation (KMF) is the largest Cooperative Dairy Federation in South India, owned and managed by milk producers of Karnataka State. KMF has over 2.19 million milk producers in over 11,870 Dairy Cooperative Societies at village level, functioning under 13 District Cooperative Milk Unions in Karnataka State. KMF is the Apex Body in Karnataka representing Dairy Farmers Co-operatives. It is the second largest dairy co-operative amongst the dairy cooperatives in the country. "*Nandini*" is the brand name of KMF [5].

Collected raw milk from village co-operative societies is stored in a number of hygienic stainless steel or aluminum cans and loaded to the vehicle allocated (size of the vehicle depends on the quantity of milk collected) to the route. These vehicles further transport milk to the main chilling centres. To avoid the bacterial growth in the raw milk, it is recommended to chill the milk from 35 ^{0}C to 10 ^{0}C (4^{0}C if transportation is after 4 hours of milking) [6]. Hence, some of the dairy co-operative societies are provided with bulk milk chillers on the only condition that the quantity of milk collected is as per the requirement mentioned by the board. Till the chilling unit, the milk is kept at room temperature.

There are several sources of heat generation inside the insulated compartment of the vehicle during transport, *e.g.* some heat leaks in through the body and its insulation. Heat gets in when the doors are opened; some heat may still be produced by the load, even after it has been cooled [7]. The different types of loads include: Transmission load, Product load, Infiltration load.

Chilling of milk means rapid cooling of raw milk to sufficiently low temperature so that the growth of micro-organisms present in the milk is checked [6]. In chilling process, the temperature of milk should be reduced to less than 10 °C. If milk has to be transported to longer distances considerable time is involved between production and heating process. During this period, milk must be protected from spoilage. Therefore, chilling is considered necessary soon after it is received at the chilling centres. There are several methods of chilling, *viz.* Can immersion Can cooling, Surface cooler, Bulk milk chiller.

There are many types of transport refrigeration systems. Eutectic system consists of hollow tubes, beams or plates filled with a eutectic solution (phase change material) to store energy and produce a cooling effect. In eutectic concept, heat absorption is provided by phase change material rather than direct expansion of refrigerant gas. The plates or beams that contain the eutectic are charged (frozen down) at night on mains power [8, 9]. Vapour compression is the most common refrigeration system used for refrigerated food transport applications. Wide range of compressor drive methods is available for mechanical refrigeration with the vapour compression cycle. They are Vehicle Alternator Unit, Direct Belt Drive, Auxiliary Alternator Unit, Auxiliary Diesel Unit [8]. Two materials generally recommended for vehicle insulation are: High-density Styrofoam and High-density polyurethane (also called PUF, Polyurethane Foam)[7].

The outer skins of the compartments may be made from various materials including Glass Reinforced Plastic (GRP). A combination of plywood and GRP, aluminum, stainless steel GI etc. [7-10] are used in chilling units.

In the current method of transportation of milk, raw milk is collected in the can and loaded directly on to the milk collecting vehicle from each of the dairy co-op societies. Collected milk is transported to chilling centre without any primary chilling at root level. Collected milk has to be cooled to 10°C or less within 4 hrs., otherwise it will affect the quality of milk. All the dairy co-op societies do not have raw milk chilling facility or bulk milk chillers of their own, which can result in wastage of the milk in case if any can of milk is spoilt. 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. This project is aimed at providing small chilling units for transportation of milk from village collection centres and also at ergonomically designing the milk van to facilitate easy loading and unloading of milk cans.

2. DATA COLLECTION, ANALYSIS AND PDS

2.1 Data collected from Dairy Co-operative Societies (DCS)

Gemba study was conducted by visiting Dairy Co-operative Societies (DCS) in villages and information was gathered by discussing with respective dairy secretaries and society members. A questionnaire was prepared and handed over for getting the responses.

2.1.1 Milk collection, storage and transportation

Step 1: In the present milk collection method, the farmers come with fresh raw milk stored in steel, aluminum or plastic containers. Samples are taken from each farmer's milk for testing and relative readings of fat and quantity is documented. Time duration of collecting and transportation is fixed by the federation. Figure 1 shows milk collection and transport cycle.

Step 2: Milk from all farmers is strained and stored in washed aluminum or steel cans of 40 liter capacity each, which belong to the DCS.
Step 3: When the collection van arrives, the cans are loaded to the vehicle and the empty cans are handed over to the respective DCS to which they belong. The vehicle then moves to other DCS on the route for further collection and then to the chilling centre. Figure 2 shows Gemba study at Dairy Co-operative Societies.

Quantity of milk collected per day
Quantities of milk collected in two surveyed routes are 1200-1400 litres/day in Golimakki route (G) and 1600 liters/day in Bilgi (B) route.

DCS present in the route
12 DCS in route G
28 DCS in route B

Milk collected at each DCS
40 – 200 liters (1-5 cans)

Distance from DCS to chilling unit
110 km on route G (one way)
160 km on route B (one way)

Duration of transport
4 hours on route G (morning 6:15am to 10:15 am, evening 6.15pm to 10.15 pm)
5 hours on route B (morning 7:15am to 12:15 am, evening 5:30pm to 10.30 pm)

Frequency of transport
Two times a day morning 6:15am to 10:15 am, evening 6.15pm to 10.15 pm, morning 7:15am to 12:15 pm, evening 5:30 pm to 10.30 pm respectively for route G and B

Fuel cost per liters of milk
Rs. 1.50 for route G and Rs.2.80 for route B respectively. The vehicles used for transport are on contract basis.

Fig. 1 Milk collection and Transport cycle

Fig. 2 Gemba study at DCS

2.2 Heat load calculation

Heat loads were calculated based on the data obtained from Dairy Co-operative Societies. Effective area of the compartment obtained was 29.54 m^2. Heat loads were calculated, which included transmission loads, infiltration load and product load, which was 10114 W. The total heat load was 11125 W for route G and 9974 W for route B.

2.3 Weight calculation

Compartment weight contributes to the overall weight of the vehicle. Different materials are used for outside and inside layers of the compartment and Polyurethane foam is sandwiched between the two layers. Calculation is done using dimensions of sheet and technical specifications of the material required for building the compartment. The approximate total weight of the compartment obtained from calculations was 1061 kg. Total load chart is given in Table 1. A suitable Vehicle was selected according to the load calculated and payload capacity of the vehicle. Figure 3 shows the selected vehicle. Table 2 shows the vehicle specifications.

Fig. 3 Vehicle selected for study

Table 1. Total load chart

Sl no	Description	Weight in kg	Remarks
1	Container	1061	Calculated
2	Rack	236	From CATIA
3	Mechanical lift (GI)	45	From CATIA
4	Human weight (2 people)	150	Approximate
5	Refrigeration unit	500	Catalogue
6	Milk	1029	Calculated
7	Milk can	208	Calculated
	Total	3229	

Table 2. Vehicle specification

Model	Tata SFC 407 EX
Fuel Tank	60 l
Complete chassis Kerb Weight with cab and load body (with spare wheel and tools as per IS:9211	2300 kg
Max. permission GVW	5950 kg
Pay load	3560 kg
Main chassis dimensions as per IS 9435	
Wheel base	3100 mm
Overall length	5050 mm
Overall width	2006 mm
Overall height	2245 mm
Overall length of load body	2883 mm

2.4 Mechanical lift

To ease the loading and unloading of milk cans from the rack, a mechanical lift was proposed. Mechanical lift is a simple handling equipment which assists the loading and unloading of milk cans from the rack. Lift has to be designed for manual operation with mechanical moving and rotating parts and also by keeping the loading and unloading time as prime concern with minimal effort to operate. The lift design should match with the vehicle interior layout, space available to operate inside and also the type of vehicle.

2.5 QFD Matrix

2.5.1 Quality Function Deployment (QFD)

QFD Matrix or house of quality is a tool which provides systematic approach to the product development process where the customer requirement and technical requirements are matched to get best possible specification by rating the parameters (highest to lowest). QFD provides inputs to generate Product Design Specification (PDS). For this product, QFD was prepared using the data collected from Dairy Co-operative Society, literature review and calculations. Figure 4 shows the QFD matrix.

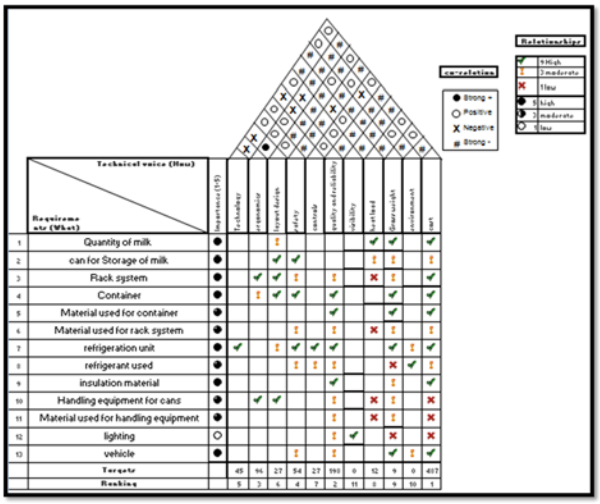

Fig. 4 QFD Matrix

2.5.2 Product Design Specification (PDS)

Product design specification (PDS) was prepared to understand the requirements for the product to be designed prior to arriving at the concepts. Table 3 shows the PDS.

2.6 Summary on data collection, analysis and PDS

Based on the number of collection centres along the route and the quantity of milk collected, the dimensions of the loading compartment were arrived. The size of the vehicle required for the route was also found out. Heat loads were obtained from calculations. Refrigeration unit was finalised using calculated heat load. Weight calculation was done, and based on that, the vehicle was selected according to its payload capacity and the gross weight of the vehicle was specified.

Figure 5 shows the current milk collection and transport cycle. The highlighted areas indicate where the problems exist. The scope of the work is to concentrate on those two areas and also to provide an alternative to the chilling plant setup.

Figure 6 shows the current loading and unloading methods of milk cans to the vehicle. Design of the vehicle interior has to be done taking care of all the constraints and also providing a feasible solution considering ergonomics and faster loading and unloading methods.

Table 3. PDS for the design

SL. No.	Factors	Product Specifications/Comments
1	Product	TATA SFC407 EX
2	Performance	Best driving quality on all roads
3	Environment	Eco friendly, with R404A refrigerant
4	Life Expectancy	5 – 10 years
5	Target	To chill the raw milk within the fixed journey time
6	Maintenance	Standardised spare parts and standard refrigeration unit
7	Packaging	Reliable and rigid, container with corrugated sheets Good interior layout
8	Size and Weight	5050 x 2006 x 2245mm ,5950 kg
9	Engineering Design	Good layout design with rack system provide sufficient storage space
10	Ergonomics	Material handling for reduced effort and easy loading of milk cans
11	Technology	Use of latest technology refrigeration
12	Materials	Used as per standards and specific for applications
13	Safety	Proven safe refrigeration unit and proper mounting
14	Economy	Suitable for mass production. Cost – Approx. Rs. 19 to 20 lakh

Fig. 1 Scope of work

Fig. 6 Current loading and unloading method

3. CONCEPT GENERATION AND SELECTION

Rough concepts for vehicle were obtained from sketches. Design was refined with proper layout, space study, and arrangement of milk cans; quantity of cans to be loaded and unloaded, assembly of compartment and refrigeration unit to the vehicle selected as the main considerations.

3.1 Concept sketches

3.1.1 Concept-1

Concept-1 was sketched by keeping two separate compartments to accommodate 12 milk cans in each compartment, Roof mounted refrigeration unit was the main consideration, and accordingly the number of racks and their layout were arrived at. Figure 6 shows concept sketch -1.

3.1.2 Concept-2

Concept-2 was sketched by keeping small cooling compartment for 5 milk cans (200 litre capacity) and separate loading compartment for 25 cans (1000 litre) as main consideration and accordingly the number of racks and their layout were arrived at. Figure 7 shows concept sketch -2.

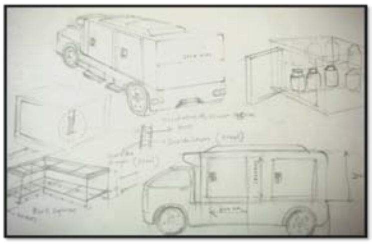

Fig. 6 Concept sketch -1 for interior

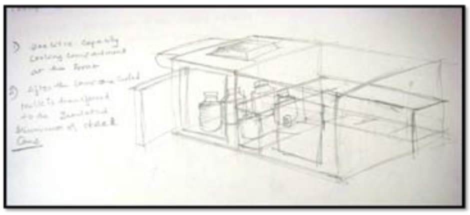

Fig. 7 Concept sketch -2 for interior

3.1.3 Concept - 3

Concept-3 was sketched by keeping single cooling and loading compartment for 25 milk cans (1000 litre capacity) and best suited refrigeration unit as main consideration, and accordingly the number of racks and their layout were arrived at. Figure 6.3 shows concept sketch -3.

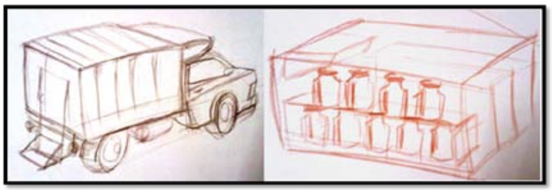

Fig. 8 Concept sketch -3 for interior

3.2 AutoCAD layout

Taking single compartment design inspired from concept sketch-3, further possible modifications such as size of the compartment, different possible layouts, rack design, suitable refrigeration unit and its assembly were considered. Also, a space study was taken into consideration. Figure 9, 10 and 11 show different vehicle layout -1,-2 and -3.

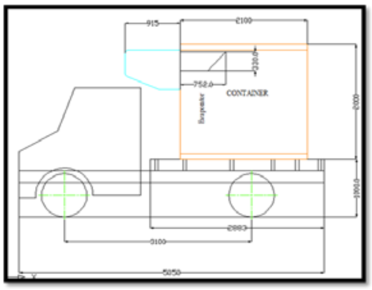

Fig. 9 Vehicle layout-1

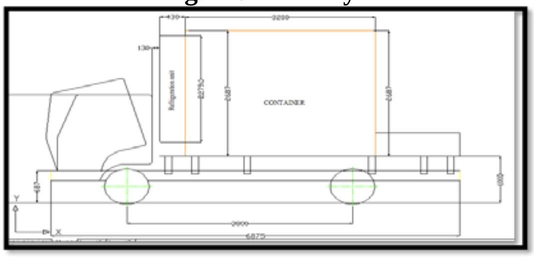

Fig. 10 Vehicle layout-2

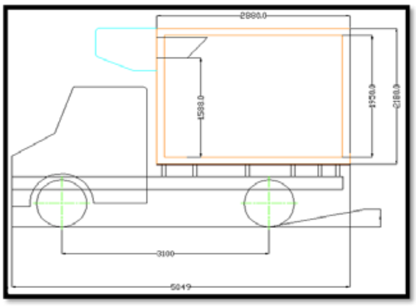

Fig. 11 Vehicle layout-3

3.2.4 Interior layout - 1

This layout was prepared keeping two stages, two row racks with 24 cans capacity. Two such racks were arranged in proper manner and with compact dimensions. Figure 12 shows the interior layout -1 with important dimensions.

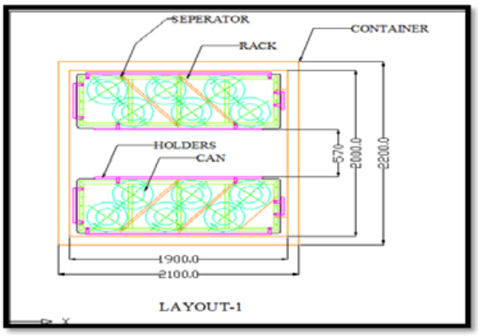

Fig. 12 Interior layout-1 of milk van

3.2.5 Interior layout – 2

This layout was prepared keeping two stages, single row rack with 24 cans capacity. Two identical racks and one rack according to the layout were arranged in proper manner and with compact dimensions. Figure 13 shows the interior layout - 2 with important dimensions.

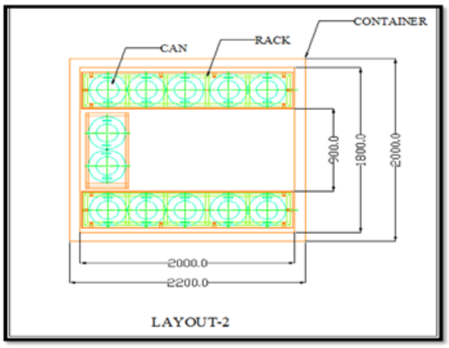

Fig. 13 Interior layout-2 of milk van

3.2.6 Interior layout - 3

This layout was prepared keeping two stages, single row rack with 24 cans capacity. Two identical racks and one rack according to the layout were arranged in proper manner and with compact dimensions. Figure 14 shows the interior layout - 3 with important dimensions.

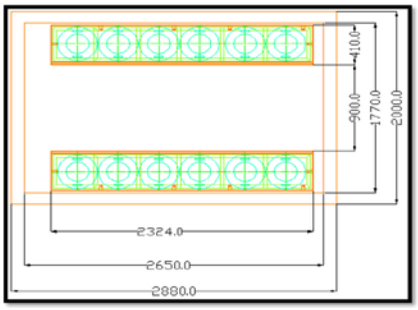

Fig. 14 Interior layout-3 of milk van

4. MODELING, ANALYSIS AND VALIDATION

From the inputs of concept sketches and AUTOCAD layout and 3D models of the vehicle, the rack and can handling equipment was generated using ALIAS and CATIA geometric modeling software. Validation for the selected final concept was done by ergonomic analysis, compatibility of mechanical lift and correctness of layout passage. Cost estimation of the project was carried out with justification for chilling the milk.

4.1 Concept -1

Concept-1 was modeled with reference to vehicle and interior layout-1 made in AUTOCAD software. Rack was designed for this concept is two stages - two row design to accommodate 12 milk cans and two such racks inside the compartment. Figure 15 shows Concept-1.

4.2 Concept -2

Concept-2 was modeled with reference to vehicle and interior layout-2 made in AUTOCAD software. Rack-1 design for this concept is single stage - single row to accommodate 10 milk cans and two such racks inside the compartment; and Rack-2 design is single stage single row to accommodate 4 milk cans. Figure 16 shows 3D Concept-2.

Fig. 15 3D view of Concept-1 of milk van

Fig. 16 3D view of Concept-2 of milk van

4.3 Concept -3

Concept-3 was modeled with reference to vehicle and interior layout-3 made in AUTOCAD software. Rack design for this concept is single stage - single row to accommodate 12 milk cans and two such racks inside the compartment.

To ease the loading and unloading of milk cans from the rack, a mechanical lift was proposed. Mechanical lift is the simple handling equipment which assists the loading and unloading of milk cans from the rack. Lift was designed for manual operation with mechanical moving and rotating parts. Lift was designed by keeping loading and unloading time as prime concern and with minimal effort to operate, designed in specific with the interior layout, space available to operate. Figure 17 shows 3D of concept-3.

Fig. 17 3D view of Concept-3 of milk van

4.4 Concept selection

Final selection of the concept depends on various parameters. Weighted ranking method, where the scores are given to a parameter which is mentioned according to the design, ease of use, loading and unloading time, ergonomics, cost etc., was used for the final concept selection. The rating method is based on 1-5 scale, 1 being the least score, 3 being moderate and 5 the highest. Scores indicated in yellow are negative weightage and to be subtracted in total score. Table 4 shows the weighted ranking method.

Table 4. Weighted ranking method

SL no	Parameter	Concept design		
		Concept 1	Concept 2	Concept 3
1	Stable design	2	2	5
2	Interior layout	2	4	5
3	Rack design	3	4	5
4	Ease of use	2	3	4
5	Material handling	-	-	5
6	Loading and unloading time	3	3	5
7	Ergonomics	2	2	5
8	Refrigeration unit cost	3	3	4
9	Compartment weight	2	2	3
10	Rack weight	3	4	4
11	Vehicle cost	3	3	3
	Total Scores	14	15	26

4.5 Validation of concept

Ergonomic analysis

The ergonomic analysis was carried out to check the design compatibility for 5th, 50th and 95th percentile humans [10] by placing manikins inside the layout with different postures and operating the mechanical lift, pushing milk can to the rack, hand grip, gap between two racks while working inside the compartment, climbing inside the compartment from outside through steps provided. Figure 18 shows ergonomic analysis.

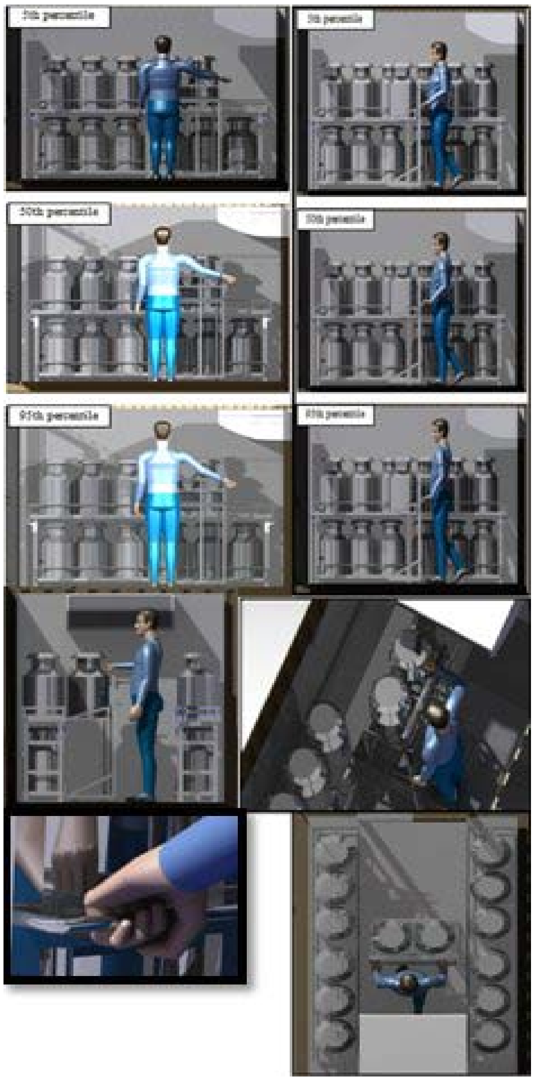

Fig. 18 Ergonomic analysis on the final concept of milk van

4.6 Mock up model preparation

A 1/10th scale Mock-up model was prepared using sun board, foam (with 80 kg/m^3 density), plastic square bead, wood and adhesive. Model preparation involved different stages as explained below:

4.6.1 Cutting and Sizing:

In this stage for the preparation of cab body and refrigeration unit of vehicle, foam was cut to the required size and shape with allowance for secondary operation (finishing). For the preparation of chassis, the plastic beads were cut to required size. For compartment, rack and mechanical lift, sun board was cut to required sizes. All the specific parts were then glued together. Figure 19(a) shows the cutting and sizing.

4.6.2 Painting:

In this stage the cab body, refrigeration unit and container were applied with putty and primer as first coat for good paint finish, and later paint was applied to all the parts. Figure 19 (b) shows the painted parts.

4.6.3 Assembly:

All the parts were assembled together using adhesive. Figure 19 (c) and 19 (d) show the assembled model (exterior and interior). Stickering was done to add features such as head lamps, tail lamps boards etc. Figure 19 shows the final mock up model.

Fig. 19 Mock-Up Model of the final concept of milk van

4.6.4 Cost estimation:

Weight calculations were carried out for the loading and unloading of cans. Cost estimation for the whole new set and chilling cost were carried out. The estimations were done taking BIS standards for milk cans and containers [11-13]. Chilling cost for a liter of milk was estimated to be INR 2.25 and INR 3.19 for route-G and route-B respectively. After chilling, the total price per liter of milk obtained was INR 28.70, which is quite reasonable.

5. CONCLUSIONS

Milk needs to be chilled to 10 °C within four hours or less otherwise bacterial growth increases thus bringing down the milk quality. Best suited refrigeration system is mechanical refrigeration system for Indian conditions. Data collected from village co-operative societies was taken for design. Heat loads obtained from calculations were 11125 W and 9974 W for route - G and route - B respectively. Concept was designed keeping ergonomics in mind and also reducing the effort and time for loading and unloading the milk cans to the vehicle. The major advantage of this project is that the milk chilled in the van can be used for secondary processing if packaging unit is located even at 4 -5 hr journey time. Chilling plant is not necessary which can be replaced by mobile chillers.

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