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DESIGN MODIFICATIONS IN COMPRESSOR OF MILK CHILLING UNIT FOR ECO-FRIENDLY REFRIGERANTS

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ABSTRACT

India is a leading developing country with flourishing refrigeration and air conditioning industry. Recently it has achieved the distinction of becoming the largest producer of milk in the world. Instant milk chilling units are used in dairy sector for chilling the milk to 4°C just after milking so that it can be preserved during further processing. R12 is mainly used in milk chillers and as per Montreal Protocol, all Ozone depleting substances like R12 are to be phased out of use before 2010. This paper presents performance analysis of refrigeration system of milk chiller for selecting a eco-friendly alternative to R12.

INTRODUCTION

The world has witnessed rapid industrialization in the two decades, which has resulted in improved quality of life of people. The economic benefits have reached to the lowest level with all enjoying long life full of comforts. But the wealth came at the cost of environment and now we are facing two big environmental problems of ozone layer depletion and global warming.

The problem of ozone depletion came into light in 1974 when ‘Roland and Molina’ accidentally discovered it. After various studies, it was confirmed that mainly Chloroflurocarbons (CFCs) are responsible for the destruction of protective ozone molecules that absorb the ultra violet radiation of sun and protect the earth from it harmful effects. After much discussions and deliberations the “Montreal Protocol” was signed under the UNEP for phasing out the use of ozone depleting CFCs which are used in refrigeration and air-conditioning equipment. As per this protocol, the developed countries have stopped the production and use of CFC in 1999 and now it is the turn of developing countries to cease the use of CFC by 2010.

Global warming of the earth has been taking place due to excessive release of green house gases like CO_2, CH_4, CFC etc. These gases are trapping the heat in earth's atmosphere resulting in temp rise and consequent abnormal weather condition witnessed in various parts of world. To tackle this problem, an international agreement is being finalized which calls for controlling the emission of green house gases.

India is a leading developing country that has a flourishing Refrigeration and air conditioning industry. At present it consumes more than 6000 MT of CFC substances like R11, R12 in various commercial and industrial refrigeration and air-conditioning equipment which will be required to be phased out by 2010. One of the important refrigeration unit is the Instant Milk Chilling Unit used by dairy sector for cooling the milk collected at collection centers to keep it fresh before dispatching it in insulated tanks to big dairy plants for processing and packing. Indian dairy sector operates through a network of small dairy cooperatives that have chilling centers of capacities ranging from 1000 to 10000 litter per day. The refrigeration units of 5000 liter and less operate on R12 and will be needed to be switched to an Eco-friendly refrigerant.

DESIGN SPECIFICATION OF MILK CHILLING UNIT

The Instant Milk Chilling Unit of Multai collection center has two units of 4000 liter capacity supplied by Alfa Laval Private Limited which cool the milk indirectly by chilled water from a big water tank. This type of refrigeration system is called Ice-bank refrigeration system and it works on R12. It is vapour compression refrigeration with evaporator coils submerged in water in a big water tank. The system is run in off peak hours and water in the tank is cooled to 0°C. When milk is received it is cooled by chilled water in plate type heat exchanger and kept in an insulated tank. The design and performance details of instant milk chilling unit designed for chilling 4000 Liters of milk per day from 35° C to 4° C are as follows:

Compressor: Freezking 750, 3 cylinder open type reciprocating compressor operating through belt drive at 580 rpm by a 7.5 hp induction motor and operates at plus 43 ° C condensing temp and minus 10 °C evaporating temp on Freon 12 gas. The running time of compressor is 16 hours per day.

Condenser: Air-cooled condenser with two air fans.

Expansion Device: The Thermostatic expansion device of suitable length for operating between receiver and evaporator.

Evaporator: Refrigerant R12 passes through submerged cooling coils in the 4000 Liters capacity water tank with all necessary fittings. The cooling capacity of the system is 12.31 kW.

The schematic arrangement of Instant Milk Chilling Unit is shown in Fig 1. The simple saturated vapour compression refrigeration cycle is used in this milk-chilling unit. The following assumptions were made for the analysis.

1 Pressure drops at compressor inlet and outlet valves are as given:

For R12, R134a and R152a	$\Delta pi = 0.1$ bar	and	$\Delta po = 0.25$ bar.
For R 290 and HCFC Refrigerants	$\Delta pi = 0.2$ bar	and	$\Delta po = 0.4$ bar.
For R600 and R600a	$\Delta pi = 0.03$ bar	and	$\Delta po = 0.05$ bar

2 Pressure drops in condenser and evaporator has been neglected.
3 No pressure and temp losses has been considered for connecting pipes.
4 There is no superheating or subcooling in the cycle.
5 The ideal isentropic and motor efficiency has been considered.

EVALUATION OF PERFORMANCE AND RESULTS

Two sets of thermodynamic calculation has been considered
Performance of the milk chilling unit with same compressor as with R12
Performance of the milk chilling unit with different refrigerants to obtain same refrigerating capacity

When a compressor designed for R12 is run with alternative refrigerant, it's volumetric efficiency will be affected and performance of the system will be changed. The volumetric efficiency of a compressor is affected by wire drawing at the valves, polytropic compression, re-expansion and leakage across the piston rings. The following equation is used to calculate the overall volumetric efficiency of compressor.

$$\text{Volumetric efficiency} = (1 + C) \{Ps / P_1\}^{1/n} - \{P_d / P_1\}^{1/n} - 0.015 \{ P_d / P_1 \}$$

In which P_s and P_d are suction and discharge pressure inside the cylinder and P_2 and P_1 are condenser and evaporator pressure and n is the index of compression and expansion which is taken equal to γ.

The results of thermodynamic calculations are presented in Tables 1 to 3. Table 1 gives the values of properties data at design conditions, viz., NBP of refrigerants, pressure ratio, specific volume at suction conditions, latent heat of vaporization at evaporator pressure and specific heat ratio for R12 and for alternative refrigerants. Table 2 lists the performance parameters for R12 along with alternative refrigerants which are chosen according to their boiling temp for comparing the performance of milk chilling unit when charged with these refrigerants in place of R12 using the same compressor. The thermodynamic properties of R12 and alternatives are taken from property generation software REFPROP version 6.0. Table3 gives the calculated performance parameters for R12 and new proposed refrigerants for the same refrigerating capacity of 12.31 kW using the vapour compression refrigeration design program CYCLE D.

Table 1 – Properties data of R12 and proposed alternatives for t_e = -10 °C and t_c = + 43 °C

Refrigerants	NBP °C	P2 / P1	V_1 In m^3/kg	H_{fg} In kJ / kg	Specific heat ratio	ODP	GWP
R 32	- 51.65	4.57	.06301	330.26	1.13	0	650
R 290	- 42.76	4.25	.1309	388	1.126	0	3
R 22	- 40.76	4.65	.06527	212.78	1.116	0.055	1500
R 12	- 29.79	4.71	.07737	157.53	1.126	1	8100
R 134a	- 26.2	5.49	.09959	205.95	1.102	0	1300
R 152a	- 25	5.42	.1709	316.94	1.134	0	260
R 124	- 11.96	6.44	.1392	164.91	1.13	0.02	480
R 600a	- 11.73	5.32	.3336	365.26	1.086	0	3
R 142b	- 9.00	5.68	.2144	223.24	1.135	0.065	2000
R 600	- 0.54	5.92	.5232	394.01	1.13	0	3

Table 2 - Calculated Performance Parameters of R12 and New Proposed Refrigerants using the same compressor as with R12 in Milk Chilling Unit

Refrigerants	Mass flow rate kg / min	Volumetric Efficiency	Discharge Temp ° C	Refrigerating capacity kW	Compressor power kW	COP
R 32	8.81	.783	72	33.04	8.75	3.87
R 290	4.45	.822	48.95	18.27	5.01	3.64
R 22	7.45	.686	64.96	18.09	4.72	3.88
R 12	6.99	.763	50.6	12.31	3.26	3.83
R 134a	4.83	.679	49.4	10.59	2.86	3.70
R 152a	3.00	.724	59.8	11.25	2.82	3.95
R 124	3.34	.686	43	5.87	1.46	4.01
R 600a	3.70	.696	43	6.40	1.73	3.70
R 142b	2.23	.675	48.6	5.80	5.76	3.97
R 600	.825	.609	43	3.66	.938	3.90

Table 3 – Calculated Performance Parameters of R 12 and New proposed Refrigerants for the same refrigerating capacity of Milk Chilling Unit

Refrigerant	Mass flow rate	Compressor power	Piston Displacement V p (m^3/min)	V_p / V_{12}	COP
R 32	3.18	3.39	12. 022	0. 372	3. 64
R 290	3.00	3.39	23. 562	0.729	3. 64
R 22	4.98	3.24	19. 503	0.601	3. 80
R 12	6.99	3.23	32. 30	1	3. 83
R 134a	5.58	3.32	33. 343	1.032	3. 71
R 152a	3.30	3.13	33. 838	1.047	3. 93
R 124	7.02	3.28	58. 631	1.815	3. 75
R 600a	3.12	3.25	62. 449	1.933	3. 79
R 142b	4.74	3.10	60. 975	1.888	3. 97
R 600	2.76	3.15	86. 642	2.682	3. 91

DISSCUSSION OF RESULTS

From Table 2, it is clear that refrigerating capacity of milk chilling unit is affected when existing R12 compressor itself is used with new proposed refrigerants. This is mainly due to change in mass flow rate of the refrigerant, which is decided by the volumetric efficiency and suction vapour volume at inlet to compressor. The latent heat of vaporization can have either a positive or negative effect on the refrigerating capacity of the unit. The higher boiling refrigerants R32, R290 and R22 give very high refrigerating capacity than the refrigerants with lower boiling temps and therefore could be possible substitute. R152a and R134a have small capacity difference and could be possibly used with increased run time.

With same compressor R124, R142b and butane perform better with increased COP and smaller compressor power but can not be used due to their very small refrigerating capacity. R32 and R22 give better COP but consume more power as compared to R12. The isentropic temp at the outlet of cylinder is also tabulated in Table 2 and both R32 and R22 have comparatively high temp as compared to R12 and will require extra cooling to protect the compressor from overheating.

From Table 3, it is clear that for same cooling effect, Refrigerants R152a, R142b and R600 give best results in the milk-chilling unit. Their COP and power consumption is better as compared to R12 but R142b and R600 require very high displacement volume therefore will require bigger compressor than R12. R152a requires only 4.7 % more volume and can be used in the system if its volumetric efficiency can be matched to give equal displacement. All other refrigerants have smaller COP and higher consumption of power. R22 has very small performance difference but require 40% small compressor for working in place of R12 in the refrigeration system of milk chilling unit.

CONCLUSION

Out of the 9 proposed refrigerants, none can be used as a drop in substitute in place of R12 in the refrigeration system of milk chilling unit. As per the analysis R152a emerges as one of the most promising refrigerant with higher system performance and an equal matching compressor displacement. It has no Ozone Depletion Potential and comparatively small Global Warming Potential. With all other refrigerants, the system will be required to be modified as per the performance results of the system with that refrigerant. But to have an ideal drop in substitute, R152a can be combined with high refrigerating capacity refrigerant R290 or high performing R142b.

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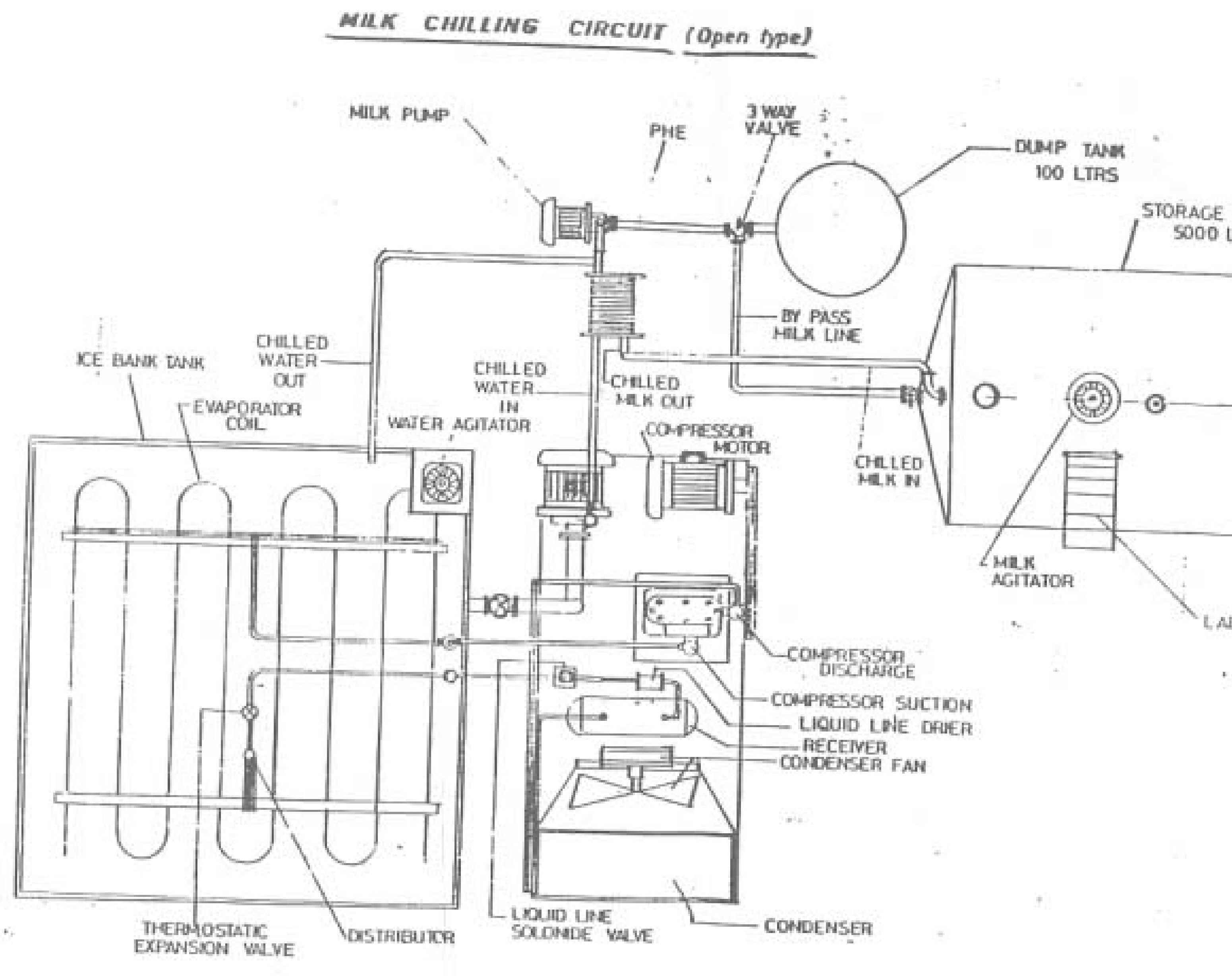

Fig. 1 Instant Milk Chilling Unit.