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Replacing harmful refrigerant R22 in a bulk milk cooler

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Abstract: Many milk coolers are presently using refrigerant R22 which has substantial ozone depleting potential along with high global warming potential. As per the commitment of Montreal and Kyoto protocol, R22 is required to be replaced by a suitable eco-friendly refrigerant and this paper explores the various options available. First the performance of 13 eco-friendly refrigerants was compared by simulating their performance with the help of CYCLE D. Then detailed study of binary and ternary mixture refrigerants has been done for selecting a Retrofit mixture for use in place of R22 in the existing milk cooler. Elucidating the performance,ODP and GWP values of refrigerants, it is clear that R1270 is best choice for replacing R22 with zero ODP and negligible GWP. Out of four mixtures, R32/R152 is best with zero ODP and low GWP.
Keywords: Refrigerant, CFC22, Retrofitting, milk cooler.

Introduction

Refrigeration plays a very vital role in dairy industry as milk and milk products are highly susceptible to bacteria growth in very short time. Fresh milk does not form any bacteria for the first 40 minutes, after that bacterium multiplies every 20 minutes in unprocessed milk. So the quality of collected milk is preserved by cooling it as quickly as possible to below 4 °C at milk collection centers with the help of Milk Coolers before dispatching it daily in insulated tanks to big plant for further processing.

Production of milk in India is very widely scattered in the rural areas and at vast distances from the places of high consumption in the urban areas. Dairy Farming as such is not a professional occupation but part of the over all agriculture operation. The hygienic conditions and environment of milk production in the rural area are still not up the desired standards. High ambient temperature throughout the year in a tropical country like India is an additional disadvantage since the bacterial growth is very rapid if the temp of milk is not brought down immediately after the production. It is very essential to cool the milk immediately after milking to maintain the quality of milk as final transporting to processing plant may take 8 hours or more from the time of milking. In fact the chilling of milk at or near the production centers is the most important factor which has influenced the growth of milk industry. The chilling of milk to about 4 °C or less is done to check the growth of bacteria and preserve the quality as produced, until it is subjected to pasteurization process. This is done at collection centers using Instant Milk Chilling Units and Bulk Milk Coolers.

Madhya Pradesh (M.P.) is one of the biggest states of India of more than 10 million people. M.P. State Dairy Co-operative Federation (MPSDCF) is the apex body of 5 milk unions of the state which collect milk from 4522 village level co-operatives with .241 million farmer members. It has collection units all over M.P with capacities ranging from 1000 to 20000 liters per day (LPD) where milk is chilled to 4°c with the help of Milk chillers before dispatching it daily in insulated tanks to big plants for processing. MPSDCF has total milk-chilling capacity of 448000 LPD and after processing, markets its milk and milk products under the trade name of 'Sanchi'. Milk Coolers, using HCFC22 as refrigerant, contribute 17.5 % of its total milk chilling capacity.

At present HCFC22 is the most widely used refrigerant in the world both for refrigeration and air-conditioning. Although HCFC's are considered to be only 5% ozone depleting refrigerant but as they contain chlorine giving it the potential to damage the ozone and therefore has been targeted since the 1990's for eventual phase out by the Montreal Protocol, an international treaty signed under the UNEP for control of substances damaging the protective Ozone Layer of the Earth (Agrawal, 2001).

In October 2000, EC Regulation no. 2037/2000 was brought into force as the last step in eliminating ozone-depleting substances (ODSs) as per the Montreal Protocol. This binding regulation is the legislative instrument used by the European Union to phase-out ozone depleting substances and stipulates that the use and sale of virgin hydro chlorofluorocarbons (HCFCs) will be banned from 1 January 2010. HCFCs (most commonly in the form of R-22) are used in a variety of refrigeration and air conditioning installations (both stationary and mobile commercial refrigeration, cold and freezing stores.

In 2007 and 2008, the U.S. Environmental Protection Agency (EPA) published an industry model of the expected HCFC market size and the related demand for R-22. Based on the market demand model , EPA too proposed rules for meeting the 2010 phase-down called for by the Montreal Protocol of R-22 and other HCFC refrigerants. The first rule regards the 2010 allocation of production and import rights of R-22. The second proposal is on the ban on production, import, and sale of R-22 in new equipment post January 1st, 2010. These rules regarding the phase out of R-22 refrigerant gas will become effective January 1st, 2010.

India became a party to the Montreal Protocol in 1993 and has since made significant progress in decreasing its dependence on CFC. Additionally, India must also begin to take steps to decrease its dependence on HCFCs. According to an accelerated HCFC phase out schedule, developing countries must begin to reduce their use of HCFCs from the baseline consumption-set at the average of 2009 and 2010 consumption (Singhal, 2008). Therefore search for alternatives for this important refrigerant is a very important area of research. Even after continuous research and development, no single refrigerant has been identified for replacing R22. Now Industry, with its need to meet various dead lines, has begun an intensive effort to adapt various mixtures to act as a long term working fluids in new equipment, and, when possible, as a drop in or retrofit alternative in existing equipment.

Objective

Harda Chilling Centre of Bhopal Dugdh Sangh has a Bulk Milk Cooler of 5000 litre per day capacity with a direct expansion vapour compression refrigeration system operating on refrigerant R22(HCFC22). In this paper, an exhaustive study has been undertaken to find a suitable eco-friendly refrigerant for replacing the harmful R22 so that milk cooler can be used for an extended time. The effort is to find a retrofit *i.e*. drop-in refrigerant which would replace R22 with minimum of cost and component change.

Case studies

Retrofitting of a milk silo refrigeration system operating on R22 has been done in New Zealand Dairy Research Institute, Palmerton North, New Zealand (Cleland & Keedwell, 1998). They have compared the performance of HCFC22 with hydrocarbon refrigerants from the Care range in a typical NZ milk silo refrigeration system under tightly controlled laboratory conditions. Energy efficiency increased by 5-8% for the hydrocarbon refrigerants trialed and there was minimal change in cooling capacity of the system if the hydrocarbon mixture is appropriately chosen. On farm trials were undertaken to confirm laboratory tests that showed the benefits of using hydrocarbons as drop in replacement to fluorocarbon refrigerants in milk silo refrigeration system (Keedwell & Cleland,1998). Only potential disadvantage of hydrocarbon refrigerant is its flammability. But milk silo refrigeration systems generally contain less than 5 kg of charge and most farm systems are located either outside or in well ventilated enclosures with restricted access. Therefore most farms would meet the criteria for use of flammable refrigerants set out in the joint Australia-NZ standards for safe use of refrigerants.

In Indonesia, number of milk cooling units have been retrofitted by Hydrocarbon refrigerants after the research work done in the Bandung Institute of Technology (Pasek *et al.,* 1990). In this research, a milk cooling unit designed for R22 was directly switched to propane/butane refrigerants (propane/isobutane and propane/ n-butane). It was found that propane/n-butane refrigerant is the most efficient followed by propane/iso-butane and R22 refrigerant.

Criteria for selection of retrofit refrigerant

An integrated approach that includes economic, performance and safety criteria will be required while finding a solution to the problem of phase out of harmful refrigerants in a developing country like India as milk is one of the basic necessities of life. Either purchase or replacement or major modification of existing equipment will add on to the cost of the milk. Hence it is a must that existing equipment with useful life in it remain in operation. Retrofitting i.e. changing over of current refrigerant by suitable alternative is the most effective solution in India. This will require a selection of a drop-in substitute as a replacement to R-22.

In principle a drop in alternative should fulfill the following criteria:

- The new refrigerant should have zero or very small ozone depleting potential along with minimum global warming potential.
- Any drop in substitute should have the same volumetric refrigeration capacity as of R-22 in the milk chiller to use the same compressor (Jung *et al.*,1999)
- The cooling unit should have matching or better coefficient of performance (C.O.P.) with the alternative refrigerant.
- The new refrigerant should be compatible with the material of construction and lubricant used in the compressor.
- The toxicity and flammability potential should be evaluated carefully before selecting an alternative. And if the refrigerant is flammable, all necessary safety measures and controls should be incorporated in the system.
- If the alternative is a mixture, it should have temperature glides less than 5 to 7^{o} C to avoid changes in composition due to any leakage.
- Availability of the alternative refrigerant with its cost will also be important factor in selection of drop in alternative.

Table 1.1. Thermodynamic & environmental properties of R22 & selected refrigerant at the design conditions of bulk milk cooler

Refrigerant	N.B.P (°C)	P.R.	Volumetric Efficiency	V_1 (m^3/kg	H_{fg}	Specific heat ratio	ODP	GWP
R142b	-9.25	5.40	.781	.154	264.8	1.13	0.065	1600
R600a	-11.61	4.94	.791	.244	443.8	1.09	0	3
R124	-11.96	5.41	.781	.0992	202	1.13	0.022	430
R227ea	-15.61	5.31	.785	.0653	167.2	1.13	0	2900
R152a	-24.02	5.04	.797	.1250	374.6	1.134	0	140
R134a	-26.07	5.09	.788	.0720	252.1	1.102	0.00015	1200
R717	-38.94	5.38	.743	.3060	1443	1.31	0	0
R22	-48.81	4.37	.827	.0492	250.2	1.13	0.055	1500
R290	-42.1	4.02	.842	.1000	472.8	1.126	0	3
R143a	-47.22	4.16	.836	.0383	244.7	1.13	0	3800
R1270	-47.69	3.90	.848	.0844	470.6	1.13	0	3
R125	-48.14	4.23	.833	.0248	180.5	1.13	.00003	2500
R32	-51.65	4.33	.829	.0479	382.6	1.13	0	650

Materials and methods

Technical detail of bulk milk cooler

The Harda Chilling Center of Bhopal Dugdh Sangh has Installed Chilling Capacity of 5000 LPD of milk. It is a Bulk Milk Cooler with direct expansion cooling

Table 1.2. Performance parameters of selected eco-friendly refrigerants when used in bulk milk cooler for giving same cooling capacity

Refrigerant	M (kg/sec)	P (kW)	QK (kW)	RE (kJ/kg)	V.R.C. (kJ/m^3)	VRC/VRC$_{12}$	DT (°C)	COP
R142b	.191	9.86	38.40	150.12	762.5	.328	76.0	2.90
R600a	.126	10.37	39.00	227.32	738.3	.318	63.3	2.76
R124	.284	10.48	39.11	100.68	792.6	.341	66.4	2.73
R227a	.452	12.36	40.99	63.35	761.8	.328	55.0	2.32
R152a	.135	10.08	38.71	212.24	1357.8	.584	89.0	2.84
R134a	.232	10.77	39.40	123.60	1352.6	.582	75.2	2.66
R717	.028	9.99	38.52	1009.36	2452.7	1.05	169.4	2.87
R22	.207	10.62	39.25	138.41	2324.6	1.00	97.7	2.70
R290	.125	11.10	39.76	229.82	1927.9	.829	74.0	2.58
R143a	.288	12.83	41.46	99.43	2168.0	.933	75.7	2.23
R1270	.121	11.53	39.76	236.60	2377.6	1.02	81.9	2.57
R125	.503	15.23	43.86	56.97	1915.1	.824	67.8	1.88
R32	.135	11.41	40.04	212.08	3672.5	1.54	118.4	2.51

system. The cooling unit of the bulk cooler is adequately designed to cool milk from 35°C to 4° C according to ISO5708 norms. The compact condensing unit is simple, easy to install and comprises of Reliable hermitic compressor Co-plant QR90 of 8TR capacity operating at 0 °C evaporating temperature and 55 °C condensing temperature (Alfa Lavel) and Charged with 14 kg of Freon22 which is injected by the expansion valve in the evaporator.

For simulation of Bulk Milk Cooler, the Copeland Compressor QR 90 input values of Isentropic Efficiency value .80, Compressor Volumetric Efficiency as calculated for selected refrigerant, Electrical Motor Efficiency of 1.0 and System Cooling Capacity of 28.64 kW are used. These values are taken from the technical data of the condensing unit and in consultation with Design Engineer of the Alfa Lavel Agri (India) Limited, Pune.

Results

Performance study of 13 alternative eco-friendly refrigerants was done using simulation programme Cycle_D which is developed by NIST (National Institute of Standard and Technology), Gaithersburg, USA and used extensively for selecting a suitable alternative refrigerant

Table 1.3. Performance simulation of binary mixtures with equal volumetric refrigeration capacity of R22 in bulk milk cooler

Refrigerant/ Mixture Ratio	M (kg/ sec)	P (kW)	Q_k (kW)	V_1 (m^3/kg)	Te (°C)	Te (°C)	P_e (kPa)	P_c (kPa)	RE (kJ/kg)	V.R.C (kJ/ m^3)	D.T. (°C)	P.R.	COP
R22	.207	10.62	39.25	.0492	0	0	498.0	2175.1	138.41	2324.6	97.7	4.37	2.70
R 32/ R142													
.63/.37	.134	10.67	39.30	.0741	11.9	12.6	466.1	2288.6	213.80	2323.8	116.5	4.91	2.68
R32/R152a													
.49/.51	.128	10.63	39.26	.0781	5.4	6.2	469.8	2254.5	223.10	2321.7	108.2	4.80	2.69
R 32/ R 600a													
.55/.45	.139	11.71	40.34	.0719	21.9	15.9	557.6	2557.4	205.94	2318.7	99.7	4.59	2.44
R 32/ R 124													
.45/.55	.188	11.26	39.89	.0530	9.4	8.5	512.2	2455.8	152.28	2311.9	101.9	4.79	2.54
R 32/ R 134a													
.39/.59	.175	10.99	39.62	.0569	4.2	4.5	501.5	2406.1	163.79	2328.6	97.5	4.80	2.60
R 32/ R 143a													
.08/.92	.271	12.76	41.39	.0377	3.7	0.5	659.8	2749.6	105.77	2336.3	79.0	4.17	2.24

Table 1.4 - Performance of ternary mixtures with equal volumetric refrigeration capacity and higher C.O.P. and small temp glides in bulk milk cooler

Refrigerant/ Mixture Ratio	M (kg/ sec)	P (kW)	Q_k (kW)	V_1 (m^3/kg)	P_e (kPa)	P_c (kPa)	Te (°C)	Te (°C)	RE (kJ/kg)	V.R.C (kJ/ m^3)	D.T. (°C)	P.R.	COP
R22	.207	10.62	39.25	.0492	498.0	2175.1	0	0	138.41	2324.6	97.7	4.37	2.70
R 32/R152a R600a													
.47/.35/.18	.141	11.07	39.70	.0699	525.7	2406.5	5.8	6.5	202.65	2336.4	97.5	4.58	2.59
R 32/ R600a/R134a													
.40/.05/.55	.176	11.01	39.64	.0562	506.2	2422.2	4.4	4.8	162.90	2314.2	97.8	4.79	2.60
R 32/ R 152a/ R 124													
.050/.35/.15	.140	10.76	39.39	.0697	490.6	2341.1	6.1	6.7	203.84	2344.3	107.1	4.77	2.66
R 32/ R152a/ R134a													
.50/.45/.05	.131	10.68	39.31	.0752	481.0	2302.3	5.4	6.4	218.32	2337.8	108.0	4.79	2.68
R 32/ R 152a/ R 142a													
.35/.40/.25	.150	10.92	39.55	.0671	497.4	2330.7	5.1	5.4	190.90	2335.1	99.8	4.69	2.62

Table 1.5. Selected retrofit refrigerant for replacing R22 in bulk milk cooler

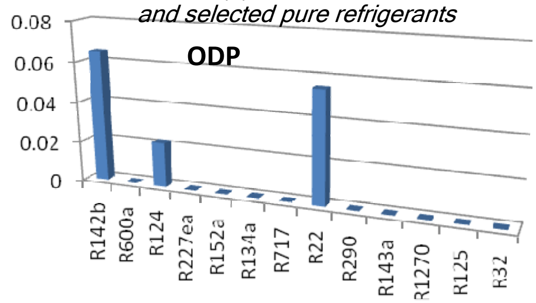
Refrigernt/ Mixture Ratio	M (kg/sec)	P (kW)	Q_k (kW)	V_1 (m^3/kg)	ΔTe (°C)	ΔTc (°C)	P_e (kPa)	P_c (kPa)	R.E. (kJ/kg)	V.R.C (kJ/ m^3)	D.T. (°C)	P.R.	COP
R22	.207	10.62	39.25	.0492	0	0	498.0	2175.1	138.41	2324.6	97.7	4.37	2.70
R1270	.124	11.38	40.65	.0844	0	0	585.9	2286.1	236.67	2377.6	81.9	3.90	2.57
R32/R152a													
.49/.51	.128	10.63	39.26	.0781	5.4	6.2	469.8	2254.5	223.10	2321.7	108.2	4.80	2.69
R 32/ R 134a													
.39/.61	.175	10.99	39.62	.0569	4.2	4.5	501.5	2406.1	163.79	2328.6	97.5	4.80	2.60
R 32/ R600a/R134a													
.40/.05/.55	.176	11.01	39.64	.0562	4.4	4.8	506.2	2422.2	162.90	2314.2	97.8	4.79	2.60
R 32/ R152a/ R134a													
.50/.45/.05	.131	10.68	39.31	.0752	5.4	6.4	481.0	2302.3	218.32	2337.8	108.0	4.79	2.68

for a vapour compression refrigeration system. The possible alternate refrigerants have been selected because of their favorable environmental properties and comparative assessment of their properties at design condition of milk cooler have been given in Table 1.1 and Graph 1.1(a &b). The performance simulations have been done with different refrigerant to obtain same cooling capacity as with R22. The results of simulation, in terms of mass flow of refrigerant (m), power consumption (P), Heat rejected in condenser (Qk), Volumetric Refrigeration Capacity, Refrigerating Effect (VRJ), Discharge Temperature at compressor outlet (Tc) and Co-efficient of Performance (COP) of the Bulk Milk Cooler when alternative refrigerants are used in place of R22, are presented in Table 1.2. Also Comparisons of COP, Mass Flow rate, Discharge Temp. at compressor outlet and requirement of Compressor displacement for R22 and selected refrigerants have been shown in Graph 1.2 (a) to Graph 1.2(d).

Table 1.6. Environmental properties of selected retrofit refrigerant

Refrigerant	O.D.P	G.W.P
R22	0.055	1500
R1270	0	3
R32/R152a (.49/.51)	0	390
R32/R134a (.39/.61)	0	986
R32/R152a/R134a (.50/.45/.05)	0	710
R32/R600a/R134a (.40/.05/.55)	0	920

Graph 1.1 (a) - ODP values of R22 and selected pure refrigerants



Discussion

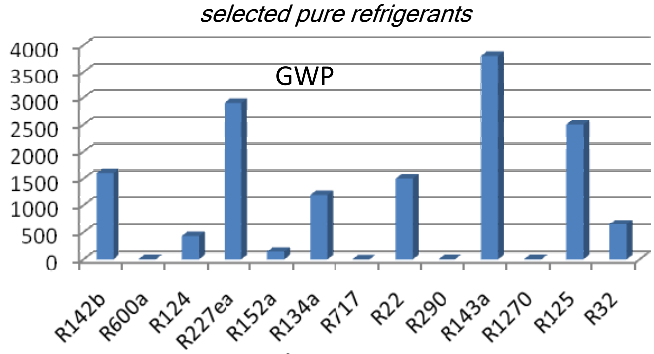
R142b has a higher pressure ratio and lower operating pressures in the system but its performance was best of all refrigerants with a very high COP of 2.90. The discharge temperature at compressor out let is 76°C as compared to 97.7°C for R22. For the equal cooling capacity, R142b system will require approximately 70% larger displacement volume as compared to R22. The R142b is compatible with the mineral oil used with R22 system.

R600a is a natural occurring hydrocarbon with very favorable environmental properties as compared to R22. It has a very high latent heat along with high specific volume. Therefore the mass flow requirement is very small. Its performance is better than R22 system with COP of 2.76 with lower discharge temperature at compressor outlet due to low specific heat ratio. This refrigerant works very well with the lubricant when it replaces R22. But because of it has high specific volume, R600a has a very small volumetric refrigeration capacity requiring 70% more compressor displacement as compared to R22.

R124 is refrigerant with low ODP and GWP value but with higher-pressure ratio and specific volume as compared to R22 at operating condition of Bulk milk cooler. Its operating pressures are lower than R22. The COP of the system with R124 is better than R22. It has a quite low discharge temperature as compared to other refrigerants. It will require 65 % higher compressor displacement than R22. Therefore the milk cooler with R124 will need a much bigger compressor.

R227ea is an HFC refrigerant with no ozone depletion but considerable global warming potential. Its pressure ratio and specific volume is higher than R22. For the same cooling capacity the mass flow requirement is very high as compared to other refrigerants .It requires a 67 % larger compressor displacement for giving same cooling capacity.

Graph 1.1 (b) - GWP values of R22 and selected pure refrigerants



R52a is an HFC refrigerant with highly

favorable environmental parameter. It performed well with a very high COP of 2.84. Its pressure ratio is higher than R22. As compared to other refrigerants, its charge requirement is very less. R152a is compatible with mineral oil but it is slightly flammable which require extra safety measures during operation. Another advantage is its lower discharge temperature than R22.For the same cooling capacity R152a requires 42% increased compressor displacement as compared to R22 compressor.

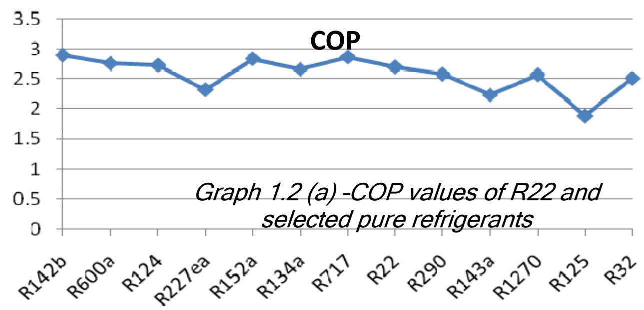
R134a is one of the most well known members of the HFC family of refrigerants. It has similar physical and thermodynamic properties to R152a. It does not have ozone depleting potential but a substantial global warming potential. R134a has compatibility problem with mineral oil and requires change of lubricant when used in a R22 system. Also it has a small volumetric refrigeration capacity than R22 therefore requires 42% higher compressor displacement for producing the same cooling effect in the milk cooler.

R22 is a HCFC refrigerant being used in Bulk milk cooler and is scheduled to be phased out in developing countries. It has a pressure ratio of 4.37 and specific volume of 0.0492. It gives COP of 2.70 and results in a high discharge temp of 97.7 °C. It is an easily available refrigerant with non-flammable property.

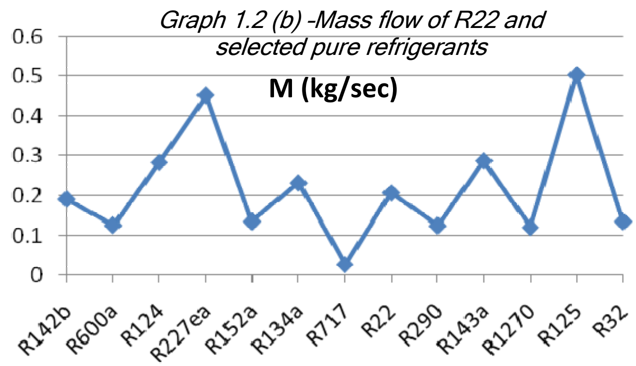
R290 is a natural refrigerant with very favorable environmental and physical properties as a possible substitute to R22 with no ozone depletion or global warming impact. It has a high volumetric efficiency associated with a small charge requirement for performing the same cooling capacity in the milk cooler. Its energy consumption is little higher than R22 resulting in lower COP of 2.58 but it gives a very favorable discharge temperature. The drawback of this refrigerant is its high flammability which will requires extra safety measures for use in place of R22 which is non flammable.

R290 is freely available and comparatively of lower cost then other substitutes. The R290 system will be compatible with the mineral oil used as a lubricant in the milk cooler. This is very important from the point of view of retrofitting cost and acceptability. But it can not be used as a direct drop in refrigerant in milk chiller as it has lower volumetric refrigeration capacity than R22. An equivalent R290 system will require 18% larger compressor displacement for giving same cooling in the system.

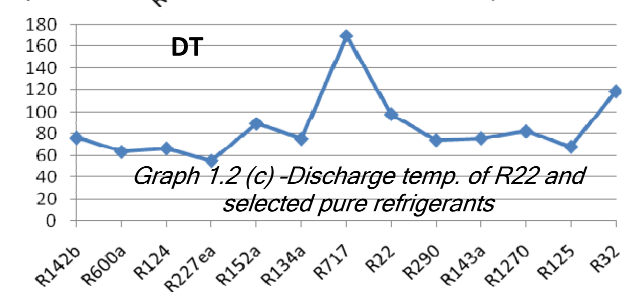
R143a is also a HFC family refrigerant but higher global warming potential than R32, R134a and R152a. It has higher pressure ratio than R22 with a higher volumetric efficiency at the designed conditions. It gives poor performance with COP of 2.23 as compared to 2.70 of R22. It also has a very high mass flow rate as compared to R22. The discharge temperature is very smaller resulting in cool operation. The operating pressures are again much higher for R143a needing extra precaution against leakage. R143a has very small volumetric refrigeration capacity difference for giving the same cooling effect in the milk chiller. The displacement required is only 7% more as compared to



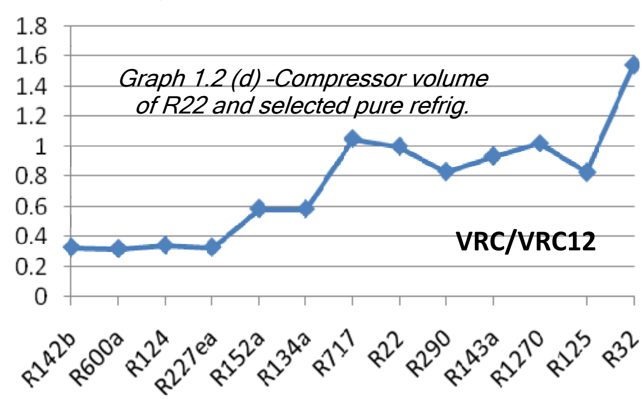
Graph 1.2 (a) -COP values of R22 and selected pure refrigerants



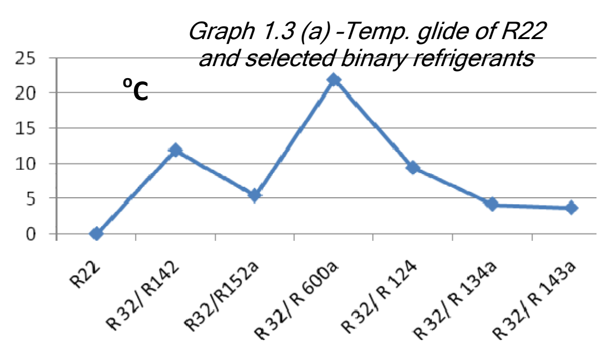
Graph 1.2 (b) -Mass flow of R22 and selected pure refrigerants



Graph 1.2 (c) -Discharge temp. of R22 and selected pure refrigerants



Graph 1.2 (d) -Compressor volume of R22 and selected pure refrig.



Graph 1.3 (a) -Temp. glide of R22 and selected binary refrigerants

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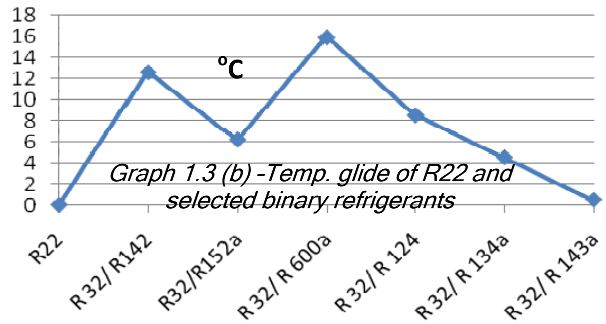
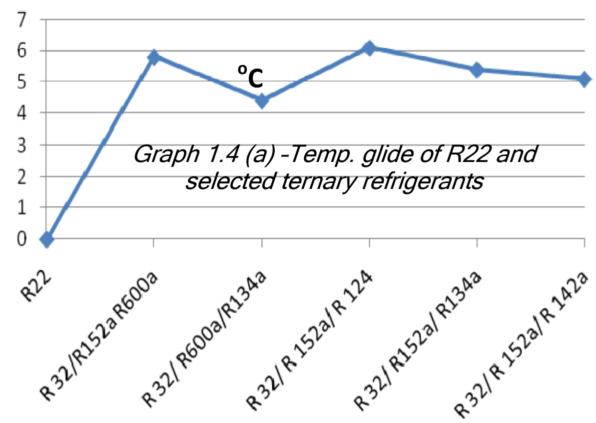
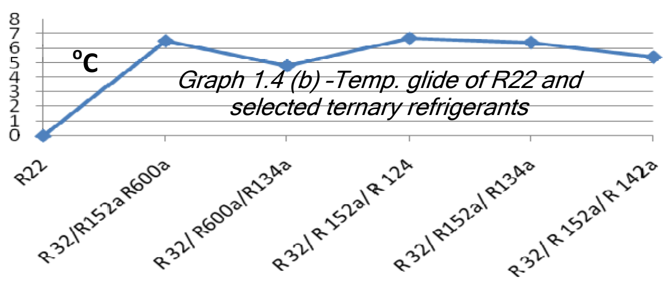
R22 compressor displacement.



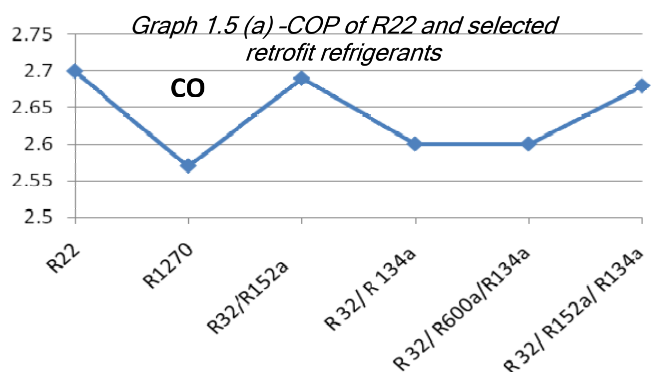
Graph 1.3 (b) -Temp. glide of R22 and selected binary refrigerants



Graph 1.4 (a) -Temp. glide of R22 and selected ternary refrigerants



Graph 1.4 (b) -Temp. glide of R22 and selected ternary refrigerants



Graph 1.5 (a) -COP of R22 and selected retrofit refrigerants

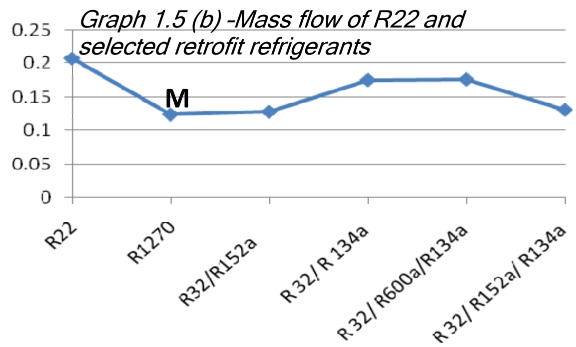
R1270 is an unsaturated hydrocarbon with no ozone depletion and a negligible global warming potential. It is the one of the two refrigerants which gives a higher cooling capacity like R32. Its COP is smaller at 2.57. It results in a low discharge temperature than R22. Its charge requirement is very low due to its very high specific volume. R1270 has a high volumetric refrigeration capacity which is just 2% more than R22 for giving the same cooling capacity in the cooler. Therefore it is the best candidate which can be used in place of R22 as a possible Retrofit refrigerant. The operating pressures are on little higher side but can be used with other system components with slight adjustment.

R125 is a lower boiling refrigerant of HFC category. It has negligible ozone depletion potential but has substantial global warming potential of 2500. It has a high volumetric efficiency due to smaller pressure ratio. It also gives quite high cooling capacity due to increased mass flow rate. It has the highest charge requirement of all the refrigerants because of its smallest specific volume. It results in smaller discharge temperature at compressor outlet, which is preferable for safe operation. The system has a very small COP as compared to R22 due to large mass floe resulting in higher power consumption in compressor. The biggest drawback is its low critical temperature which is very near to the condensing temp of 55°C .For the same cooling capacity, the R125 system will require 18% large compressor displacement.

R32 is a HFC refrigerant with zero ozone depletion effect and very small global warming potential. It has small pressure ratio as compared to R22, which results into increased volumetric efficiency of the compressor. It has a co-efficient of performance of 2.51 as compared to 2.70 of R22 refrigerant but gives a very high discharge temperature. This may require extra cooling of compressor for smooth operation. The volumetric refrigeration capacity is very high with R32. Therefore for the same cooling capacity, it will require 58% smaller compressor displacement as compared to R22.

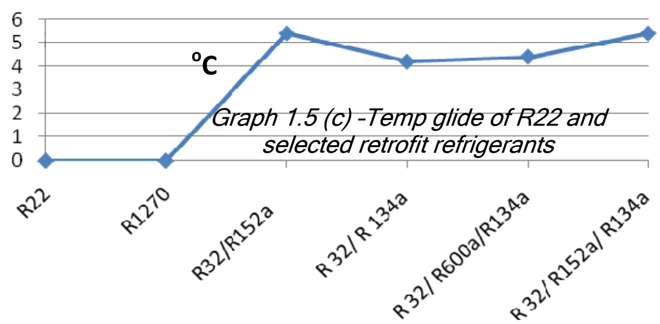
From the analysis of the results of simulation of pure refrigerants, it is clear that refrigerant Propylene (R1270) has a very similar thermodynamic property refrigerant that can be used in place of R22 in the Bulk Milk Cooler. But the co-efficient of performance of R1270 is small as compared to R22 and therefore it will increase the consumption of power, which will contribute, to the problem of Global Warming. R1270 is very flammable (A3) also causing problem in using it without strict extra safety measures. The efforts should be in finding a refrigerant which can increase the efficiency i e COP of the system and with limited flammability which can be safely managed. The solution could be in using a mixture refrigerant consisting of any two or three pure refrigerants, which will give an increased performance in terms of COP and desired system compatibility in terms of flammability.

From the analysis it is clear that there are refrigerants which give improved performance in terms of COP and they are also less flammable like R142b and R152a. But because of their lower volumetric refrigeration capacity, they can not be used in pure form in place of R22. But by combining it with a higher volumetric refrigeration capacity, a refrigerant mixture can be prepared which can be an ideal Retrofit candidate to replace R22. R32 is a higher volumetric refrigeration capacity refrigerant, which can be combined with a higher performance, but lower volumetric refrigeration capacity refrigerant. The R142b, R152a, R124 and R600a are selected for mixture study. R290, R143a and R 134a refrigerants have also been selected for further study as these have been associated with mixture refrigerants being widely researched for finding a most suitable refrigerant mixture as an ideal replacement of R22.



Graph 1.5 (b) -Mass flow of R22 and selected retrofit refrigerants

The performance of Binary mixtures, combining R32 with R142b, R152a, R600a, R124, R134a and R143a, has been studied by simulation of the performance of Bulk Milk Cooler. The analysis of R290/R32 binary mixture was not possible because their mixture had critical temperatures very near to the condensing temp of the refrigeration cycle. The Binary combination of R1270 with other refrigerants was not possible as R1270 has a nearly equal volumetric refrigeration capacity to R22 and therefore binary combinations give a pure R1270 results. The simulations of binary mixtures have been done for giving the same cooling capacity. The volumetric efficiency of the mixture refrigerants has been taken as the average of the constituent refrigerants. Table 1.3 shows the Binary mixture results with equal Volumetric Refrigeration Capacity of R22 in the Bulk milk Cooler. These mixtures can theoretically replace R22 in the Bulk milk cooler but none of the refrigerants give better result in terms of C.O.P. of the system as compared to R22. This proves the research results of last several years that it is very difficult to find a suitable eco-friendly alternative for replacing R22 in the refrigeration application. From practical application point of view, high temp glide mixtures should not be used in practical applications. This is necessary to avoid changes in the composition of the mixtures due to unavoidable leakage in any system. The mixture of R32/R142b gives a temperature glides of 11.9°C and 12.6 °C respectively in evaporator and condenser and will not be suitable retrofit candidate. Therefore only those mixtures with temperature glides in the range of 5°C to 7°C and with C.O.P higher than 2.57 are being selected as Retrofit refrigerant for replacing R22 and their comparative temp glides have been shown in Graph 1.3(a&b) Two binary mixtures namely R32/R134a and R32/R152a mixtures are possible Retrofit refrigerant which can be practically used for replacing the R22 in the refrigeration system of Bulk Milk Cooler. R32/R152a requires a smaller charge for giving the same cooling capacity of the milk chiller as compared to R32/R134a mixture. But both results in higher discharge temperature at the outlet of condenser as compared to R22. The R32/R152a mixture suction pressure is slightly smaller and R32/R134a mixture suction pressure is slightly higher than R22 system.



Graph 1.5 (c) -Temp glide of R22 and selected retrofit refrigerants

From the study of binary refrigerants, it is clear that all binary mixtures give lower C.O.P. values with a much higher discharge temperatures at outlet of compressor. The ternary mixtures combination of selected mixture may give a more efficient refrigerant, which can be used for replacing R22 in the Bulk Milk Cooler. The R32 has been combined with two lower volumetric refrigeration capacity fluids at a time to have 15 ternary combinations of the selected refrigerants. The mixture ratios were altered to get a combination with matching volumetric refrigeration capacity of R22 in milk cooler. 15 Ternary mixtures with matching refrigeration capacity but with varying degree of temperature glides of 5°C to 13 °C were identified and studied. Ternary mixtures give better results than binary mixtures with higher C.O.P. values. The C.O.P. of many mixtures is higher than C.O.P. of pure possible refrigerant R1270 (with C.O.P. of 2.57). Therefore all ternary mixtures with equal or higher C.O.P. than 2.57 and with temp glides in the range 5°C to 7°C can be selected as possible retrofit ternary refrigerant and have been given in Table 1.4 and Temp Glides variation have been shown in Graph 1.4(a&b).

Out of the five ternary mixtures, refrigerants mixtures R32/R152a/R134a and R 32/ R600a/R134a give best performance results with highest C.O.P. of 2.68 and 2.60 are selected to replace R22 in milk cooler. These refrigerants require smaller charge as compared to R22 because of their large refrigerating effect in the cycle. The operating suction pressures in the system of the selected refrigerants are close to R22 suction pressure but discharge pressures are at slightly higher sides.

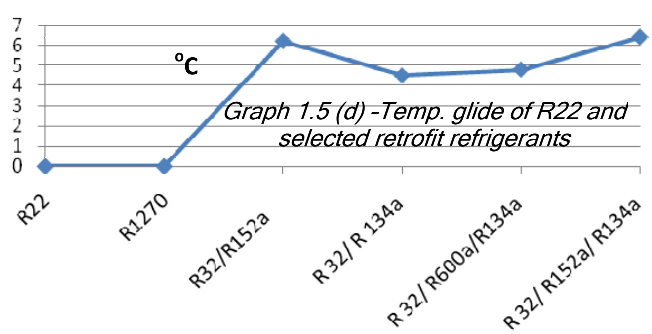
Conclusion

Now all the five Retrofit refrigerants have been tabulated in Table 1.5 for their comparative assessment of performance. Also comparison of their environmental, thermo physical and safety properties is done (Table 1.6; Graph 1.5(a) to Graph1.5(e)) for achieving the objectives of the research. From the study of the ODP and GWP values of refrigerants given in table, it is clear that R1270 is best choice for replacing R22 with zero ODP and negligible GWP. Out of four mixtures R32/R152 mixture is best with zero ODP and low GWP.

The Safety requirement of the refrigerants will be much more stringent as compared to R22 as all the five retrofit refrigerants are flammable. R1270 and R600a are highly flammable (A3), R134a is non-flammable (A1) and R32 and R152a are slightly flammable (A2). But all these are non toxic as R22 (Agrawal & Dave,1999).

The oil compatibility of the selected Retrofit Refrigerants is very important factor and should be carefully considered. Propylene (R1270) and Isobutane (R600a) are hydrocarbon refrigerants and fully compatible with the mineral oil used with R22. But HFC refrigerants R32 and R134a are not compatible with mineral oil. But HFC refrigerant R152a gives good results with mineral oil also (McLindon & Didion, 1987). Therefore out of the five selected Retrofit refrigerants only R32/R134a binary refrigerant will require a change of lubricant used. All four other Retrofit refrigerants can be used in place of R22 without change of lubricant in the refrigeration system of Bulk Milk Cooler.

The performance of the identified Retrofit refrigerants will be tested by following the Cooling Test Method given in International Standards ISO- 5708. Then the best performing refrigerant can be selected for replacing refrigerant R22 in the milk cooler.



Graph 1.5 (d) -Temp. glide of R22 and selected retrofit refrigerants

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References

1. Agarwal Alka and Dave RK (1999) Alternatives to CFC: a discussion of options. In: 20th Intl. Conf. Refrigeration, Sept. 19-24, Sydney, Australia.
2. Agrawal RS (2001) Impact of Montreal Protocol on refrigeration and air conditioning industry. In: Proc, Intl. Conf. on Emerging Technol. in Air - Conditioning & Refrigeration, New Delhi, India, Sept 26-28. pp:13-25.
3. Cleland J and Keedwell RW (1998) Use of HC refrigerants in on farm milk cooling equipment. *AIRAH J.* 52 (7)19-23.
4. Jung DS and Radermacher R (1991) Performance simulation of single evaporator domestic refrigerators charged with pure and mixed refrigerants. *Intl. J. Refrigeration*. 14 (3), 223- 231.
5. Keedwell RW and Cleland DJ (1998) Use of hydrocarbon refrigerants to replace HCFC22 in on farm milk cooling equipment. In: Proc. IRHACE Technical Conf., Nelson, NewZeland, April. pp:10-18.
6. McLindon MO and Didion DA (1987) Quest for alternatives. *ASHRAE J.* 29 (12), 32-36, 38, 40 & 42.
7. Pasek AD, Suwono A and Tandian HM (1999) Indonesian experience in retrofitting some milk coolers. In: Proc. Seminar on ODS phase out-Bali. Indonesia, May 5-7. pp: 124-134.
8. Singhal Kapil (2008) The R12 and R22 phase out in India: preparing for critical changes in the refrigerant landscape. *Air-conditioning & Refrigeration J.* 11 (4), 103-106.

Graph 1.5 (e) -ODP & GWP of R22 and selected retrofit refrigerants