

A Review on Need for Efficient Cold Chain Logistics

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Abstract: The paper reviews about the agricultural waste and need for cold chain logistics and role of this logistics on preventing the microbial degradation of the perishable agricultural products and preservation of them with controlled temperature shipment. And also on the design of mobile refrigerators and proposes an approach of utilizing R290 as a refrigerant with an overview of comparison of thermodynamic properties with prevalent refrigerants and hints its associated challenges.

Keywords: Logistics, Relative Humidity, Refrigerant, cooling load, R-Value, Coefficient of Performance, Frost, Eutectic blocks, Phase Changing Materials (PCM).

1. Introduction

The current world population being 7.7 billion alone, in India it's expected to reach 1.6 from 1.2 billion by 2050. And so will be equal demand of food and fodder. Moreover, agriculture being main source of livelihood for maximum population in India. The gross value added by agriculture, forestry and fishing is estimated to be \$274.68 billion in fiscal year18. And food processing sector registered with larger number of factories, the exports with compound annual growth-rate of 16.45% reached 38.21 billion in fiscal year18. Accounting 32% of Country's total food market still 40% of the produce deteriorates before reaching the consumers from the harvest leading to wastage of agricultural produce. The call for nutritious, organic, fresh agricultural products has been incremented as more food consciousness developed in the population with time. Agricultural products like green leafy vegetables, tomatoes, onions, etc. which play significant role in people's diet come under category of perishable goods. Being prone to deterioration by bacterial and enzymatic activities it's necessary to maintain the freshness of the product till it reaches to the customers. However, observing the supply chain structure in India the product before reaching customers it passes through ~ 10 markets. And to retain the shelf life of the product we rely on preserving it in cold storage and chemical additives (preservatives) and also to make sure to maintain the organicity of the commodities making it a potential export. Though enough care is taken during preharvest processing, the transport of these commodities at distant places to suite up growing urban demand for food products, we see greater rate of degradation during the transport due to inadequate infrastructure and major

mismanagement leading to discarding of the product either at market places or by consumers resulting in wastage of the products consequently higher rate of price fluctuation in agricultural products. For example: Delhi Mandis and wholesale markets receive truck shipments that arrive from as far as 72 hours away. Poor roads and highways from origin to destination causes entire load rot due to delay. Though initially few percent of deterioration is already present before harvest and this increases it further and thus cold transport comes into picture where it uses refrigeration systems and extend the shelf life of these perishable goods and this cold transport is significant, Though it does not eliminate the spoilage agents rather greatly reduces their activity.

2. Literature survey

The University of Florida Research Centre for food distribution[5] conducted an experiment on delaying a fully loaded truck with perishable produce for 4 hours with both pre-cooled produce and also with non-precooled produce and they notice that they obtained 92% waste and was not because of the physical, chemical attribute of the produce but due to poor handling of it in growers/shippers section and as a retailers only picks up fresher stocks, states the importance and necessity of efficient cold chain logistics in reducing advanced shelf life losses.

M Cecilia do Nascimento Nunes, Mike Nicometo, Jean Pierre and Ismail Uysal:[11] In their paper at Royal Society Publishing focused on blueberries produce of Mexico, where temperature monitored pallets containing blueberries kept under study and data were gathered throughout normal harvest and post-harvest operation and over 99% produce qualified freshness requirements before processing and 57% wastage was noted after it is delivered at longest logistic destination even after following first in first out(FIFO) approach. And at the end of the destination the monitoring system found wide variety of temperature in each of the pallets and concluded that pallets were not pre-cooled adequately and also residual field heat is to be removed, as the partially pre-cooled pallets where subjected to degrade even after ambient perfect cooling temperature was maintained in the transport and analysis of cut to cool segment indicating the importance of pre-cooling of produce would influence the shelf life of the produce and notifying the products

to be enclosed at lower temperature also adding up when for 4 days the strawberries held at 10-20°C and 95 % RH degrade in faster pace than that held at 10-20°C at 75% or 85% relative humidity coning that even maintaining relative humidity is also equally important in preservation of food products, also stating lower the RH higher the weight lost and lower will be the content of bioactive compounds.

Peter Sahupala and Reinyelda D. Latuheru: [1] have worked with cold storage design container with R12 refrigerant ,vapor-compression cycle and theoretically explained the design for single container of 12 tonnes loading capacity truck with shrimps stored having 10°C cooling temperature, 5°C with superheated temperature and super cooled temperature with 35°C refrigerant temperature in condenser and 5°C in evaporator and 0.8MPa and 0.4MPa pressures respectively have obtained cooling load of 50.254 kW with 4.76 COP and this highlighting the refrigeration system application in food preservation such i.e., shrimp which was frozen and then subjected to lower temperature in cold storage.

C S Chaudhari, S N Supali [2] have made a comparative analysis on performance of R22 and R290 on vapor compression cycle at constant condensing temperature and different evaporating temperature providing an improved life of compressor R290 has given out lower discharged temperature and COP being nearly equal to that of R22 even when the mass flow rate of R290 was reduced by half indicating R290 is better substitute for conventional refrigerant and has better thermal and physical properties and also environmental friendly. RY Maharajan and SA Borikar[7] have made an analysis on performance of R134a domestic refrigerator with R290 and obtained and concluded that R290 mixture is better at all operating condition and it's a best replacement.

3. Design of truck



Fig. 1. Vapor compression cycle- refrigerated truck

The approach proposed in this paper focuses on the theoretical design of a single compartment container with R290 as refrigerant; the insulation, drainage, sealing and drive system are as follows:

For medium sized cold transport unit of 9×5.5×6ft dimension. We need perfect insulation so that the storage is never in influence with the exterior atmosphere conditions.

Considering the insulation, the resistance to heat flow must be higher enough indicated by R value. Higher the R value less will be the cooling load and R-25 to 30 would suffice the necessity and the sandwich of polyisocyanurate of approximate 6.8/inch. R-value where it stays till 6.5/inch after 5-10 years on the walls and extruded polystyrene on the floor where it stays ~6/inch R value (conventionally used were Polyurethane).

Fiber glass batt insulation to be avoided as the moisture seeps into it and will create molds and allow air to leak out resulting in higher demand of cooling load. This rigid foam is attached over the studs leaving about 2.5-3 inches vacuum spacing and interior steel and aluminium alloy layers. Usually the seams between the insulation sheets can be avoided by overlapping multiple layers of foam to create effective barrier and the floor is insulated with sandwich of Styrofoam porch painted plywood with edges covered by metal lining (baseboard) and tilted floor towards the door would allow the flow the dripped water from the stock to flow outside and thus acts like a drainage option Johnson's tread flooring options will well suited for the air to pass beneath the pallets so as to maintain uniform temperature at all points in the crate and as the crates are being banged over the area during loading it is necessary to protect the Styrofoam with sheathing by fiber glass or COX plywood as an additional protective layer.

And thus the exterior design will be checked and sealing will be done when interiors are done. The doors are provided with gasket, the structure is sealed by caulking, foam pipe insulation between conditioner cabinet and the walls is necessary so to make sure there're no holes to atmospheric air to seep through in. And to make sure the door opens towards outside and able to swing freely and insulation of the doors should be done to at least around R-25 with associated door drip cap and the automatic door closing system to be implied [performance of foam deteriorates 3 to 5% a year].

A set temperature is maintained by figoblocks-eutectic beams at the top. And strip or curtains are being attached to the door so as to prevent the humidified air entering into the storage unit whenever the door gets opened consequently the entry of moist air from the external surroundings results in increase in humidity in the inside area of the storage unit which can be reduced by attaching a dehumidifier.

And the power source is obtained by an alternator linked inverter at the bottom, where the driving shaft is connected to the alternator and sufficient amount of electricity is generated as the truck moves and associated 3 phase electric plugs are provided at both inside and outside (to obtain shore power which truck is halt).And an automated defrost button is provided to slash the frost developed over the coils of the refrigerator unit provided only when the truck is running and made ensured that temperature is maintained at 43°C (and with circuit breaker at the end) and as defrost cycle and the compressor should restart [by voltage up by running truck engine].

The storage unit would be well-equipped with biosensors gas

sensors and fluorescent oxygen sensors as the refrigerant used will be R290 with flammability it's very important to have exhaust proof alarms and external shut down management. And trending IOT applications can also be utilized to keep on track with the logistics whereabouts and security issues.

And the refrigerant conventionally used are R-12/R-22 but we intend to utilize R290 (Propane) as a refrigerant and R290 is being highlighted because of it being stable, from thermodynamic, thermo-economic attributes and non-reactive, non-carcinogenic, non-mutagenic characteristics.

And R290 has composition of:

- Propane $\geq 99.5\%$ volume
- Isobutane $\leq 0.4\%$
- n-butane $\leq 0.15\%$
- C4 unsaturates $\leq 0.019\%$

4. Need for R290

In Brazilian magazine "engenharia e arquitetura" Anessandro da Silva, from Bitzer Brazil highlights the attributes of R290 and need for shifting from convention of R12, R22, R134a to R290 because of the propane natural occurring component posing zero threat in destruction of ozone layer and global warming potential being negligible i.e., GWP 3, and with their higher solubility with lubricants and ester oils, having high purity of \geq maintaining higher shelf life of the units (refrigerant units say compressor due to its non-corrosive property), and as the R290 gives lower volumetric capacity which is lesser than conventional R22 and R12 by 15% and high cooling effect and performance is observed with lesser mass flow rate.

All these make it a dominant mixture comparatively and safe to use when proper protocols are followed like passing the nitrogen gas through the compressor units prior refilling of the refrigerant, implementing gauges and leak identification systems. To support the above the comparison of R290 with conventional refrigerants is given in table 1,

- Latent heat of evaporation of R290 is higher than that of R22 by 80 % and R12 by 150% at a normal boiling point.
- The higher latent heat of evaporation indicates lower refrigerant mass requirement.
- The lower the requirement of refrigerant mass then lower friction and better heat transfer coefficients in evaporator and condenser.
- Higher thermal conductivity improves the performance of condenser and evaporator.
- The higher specific heat of R290 gives lower discharge temperature
- High miscibility with oils it makes one good refrigerant.

As the refrigerant R290 possess high critical pressure and temperature, low boiling point low specific volume, high conductivity, and high miscibility with oils it makes one good refrigerant.

Table 1
Comparison of R290 with conventional refrigerants

Properties	R12	R22	R290
Molecular weight (g/mol)	120.91	86.47	44.1
Critical point			
T (°C)	111.8	96.15	96.68
P (bar)	41.25	49.71	42.48
ρ (kg/m ³)	557.211	520.89	220.48
Triple point			
T	-157.05	-157.42	-187.62
P	0	0	0
Solid phase			
MP (°C)	-158	-157.42	-187.68
Gas phase			
Liquid density (kg/m ³)	1487	1409.17	580.88
Boiling point (°C)	-29.75	-40.81	-42.11
Latent heat of vaporization(at BP) (kJ/kg)	166.17	233.75	425.59
Gas phase			
Z compressibility	0.97	0.98	0.98
γ	1.15	1.2	1.15
Gas density at BP (kg/m ³)	6.29	4.7	2.42
Density	5.54	3.94	2.01
CP (kJ/kg K)	0.59	0.64	1.58
CV (kJ/kg K)	0.51	0.53	1.38
Gas equivalent (kg/m ³)	6.29	4.7	2.42
Specific gravity	4.3	3	1.55
Specific volume (m ³ /kg)	0.18	0.25	0.5
Thermal conductivity (MW/m K)	8.73	9.15	15.65
Vapor pressure (bar)	3.08	4.97	4.75

5. Advantages

1. The cold transport logistics not only adds up gross value on food processing but also plays a major role in connecting agricultural, commercial and industrial sectors.
2. The logistics effectively links farmers to markets and transform the global trade dynamics and lifestyles by satisfying demand by modern industrialized society.
3. High temperature countries that lie in subtropical and tropical region losses 50% of agricultural produce only due to degradation of food and this can be reduced as more and more research and development on this continues with time.
4. The selection of R290 initiating phasing out of R-12, R-22 refrigerants cascading resultants would be fruitful in regarding prevention of environment pollution and ozone depletion.
5. These can provide controlled temperature from -18 to 15° C and versatile enough for all agricultural produce, dairy and also pharmaceutical products.
6. The shelf life of containers is 10+ years and also is less dense due to usage of aluminium, resulting in less tyre wear and more mileage.
7. Fresh food arrives fresh as the agricultural produce being supplied fresh when demanded gives justified profit to farmers.
8. Millions of food, health supplies gets exported and thus we can see inflation in cold chain economy.
9. The PCM (phase changing material), eutectic plates in

- container acts as backup for around 4 hrs when the refrigerating cycle is stopped by any malfunctioning/technical casualties. And for smaller distances the transport can be done without refrigeration and by only help of these eutectic beams.
10. IOT introduced in this fraternity can have track over change in temperature leakage issue and the load being delivered at destination every action and minute changes can be monitored.
 11. Alternator usage will cut extra power supply and cost effective compared to units run by auxiliary driving system like diesel engine etc.

6. Disadvantages

1. The cold storage will reduce its efficiency if correct sealing of cracks and correct insulation at the corners, sheathing and efficient drainage is not provided.
 2. Good air circulation and loading protocols are critical to performance of the unit to maintain proper product temperature.
 3. Periodic maintenance of the complete unit is required like checking debris at evaporator fins, condenser surface load imperfection etc.
 4. When battery voltage is low and where truck is still connected to shore power the compressor will not run on mobile power.
 5. Frost ice gets deposited on plate surface due to moisture content and requires periodic cleaning.
 6. The refrigerant R290 is not compatible with elastomers like chloroprene, isoprene polyurethane, and plastics like polyvinyl chloride, polycarbonates.
 7. The refrigerant is flammable as it's denser than air, whenever there is leak, it gets accumulated at lowest point and their potential lubrication problem, overheating, slugging and also contamination and chances of explosion of it gets in contact with spark, flame and this could be compensated by using required leakage sensors and leakage protocols.
 8. This is not a drop in refrigerant, there's need of unique designed components of the refrigerating unit for this R290 refrigerant due to its flammability property with enclosed wired system and made sure no open electrical component is exposed with adequate earth bonds. Thus making the fabrication cumbersome.
 9. Operational responsibility is high usually 4 quarterly inspections are required each year.
 10. If there is leakage of gases when truck is located in enclosed place, there's a potential chance of an explosion would occur and someone opens the door as oxygen seeps into it.
- consequently ravishes the economy, quality of diet, employment opportunities and enabling market access and more capital reflow at several areas.
2. The refrigerant selected is dominant in its physical and thermal properties with minimal impact on ozone depletion and global warming leaving lesser carbon foot-print attracting environmentalistic customers.
 3. Lower discharge temperature improves the life of the compressor by improving stability of the refrigerant and lubricant.
 4. It was observed that R290 gives lower discharge temperature hence improves the life of compressor.
 5. Refrigerant mass flow rate required with R290 is lower by 50 % compared to R22.
 6. Naturally acceptable domestic agricultural produce can reach people residing far away from food production area near the point of freshness as possible. (and resulting lesser geopolitical tensions and potential medium to global trade).
 7. The phase changing materials i.e., eutectic units will suffice enough cooling effect as back up.
 8. The implementation of IOT smart sensor and leakage prevention units would compromise the chances of casualties as propane is flammable.
 9. As auxiliary alternator unit is utilized where there is less emission cost effective compare to auxiliary diesel unit.
 10. Frequent re-opening of doors must be avoided and perfect precooling methodology must be used and dehumidifiers are kept in the storage unit to maintain required controlled humidity.
 11. External factors also influence the perishability of the agricultural products as the microbes responsible for degradation settles in cuts in the products before harvesting, while transporting, grading of products into fresh, rotten, just rotten must be done, and mechanization of grading would reduce the efforts as currently manual grading is done thus product being rotted easily.
 12. Introduction of silo-bags would reduce the above risks and also prevent insect penetration as it used in conventional jute bags.
 13. Usage of hooks to load unload the agricultural products must be avoided so as to prevent contact with external environment and oxidation but handles or ears must be provided to jute bags so as to prevent the above habit.
 14. The long distance logistics routes, the storage unit are made to wait hours by RTA and sell unit which result in delay in delivering.
 15. The logistics construction are not emerging colorfully due to less Govt. support, lack of professionalism, less experienced workers, lack of influential third party logistic leader, high logistic cost, and no participatory

7. Conclusion

1. The immense agricultural waste can be reduced by employing efficient working cold transport

- analysis.
16. Well planned routine algorithm for the supply of produced from the logistic reduces the early degradation of the commodities.
 17. As R290 is flammable gas regulating norms must be establishes so any company with faulty design must not be encouraged (as the leakage arises due to continuous vibration of vehicles) leakage condition are high a 20-30 % per year.
 18. Though new approaches have been emerged with mobile refrigeration with lesser cooling load where thermoelectric refrigeration and refrigeration by magnets where utilized but due to the scarcity of the magneto caloric components and highly complex fabrication methodologies we set up our units with cost effective and feasible vapor compression cycles, and welcome any new cost-effective methodology.

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