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TECHNO-ECONOMIC ANALYSIS OF VARIOUS TECHNOLOGY OPTIONS FOR RURAL COLD STORAGE IN INDIA

SPARSH TRIPATHI, AYUSH MISHRA, SHARIQ KHAN, DEBOJYOTI SEN[2]

Asst Prof,IMSEC Ghaziabad[2]

ABSTRACT: This is a study on the various renewable energy technology options for operating a cold storage efficiently and cost effectively. This helps the farmer community and India as a whole to reduce the post harvest losses particularly fruits and vegetables. Cold storage is a better option in storing the fresh produce immediately after the harvest season. Sometimes there might be the situation of glut and under-pricing of produce in the market which may lead to reduced returns to the farmer. At these times, they can store their produce in cold storages near their farms instead of selling at unremunerative prices. But the power supply is erratic in the rural India still making cold storages difficult to operate which require uninterrupted power supply

Key words: Cold storage, cooling generation cost, Techno-economic analysis, solar thermal, Biomass gasifier

I. INTRODUCTION

India is a country which is one of the largest producer of fruits & vegetables. It consists of about 18% of total agricultural output of our country. A large proportion of this produce gets wasted every year due to inefficient transport infrastructure & lack of COLD STORAGE facilities.

This leads to a great loss to farmers as well as has an adverse effect on INDIA's GDP. Government of INDIA is launching various programmes for increasing the output but without proper arrangements for storage of this increased production all these efforts are in vain. Since every human being has one basic need i.e. ,food which is of perishable nature it is essential to develop an efficient COLD STORAGE infrastructure.

The problems with conventional COLD STORAGE are-

1. Loss of Moisture
2. Physical breakdown of tissues
3. Chemical changes
4. Bacterial & Yeast on or in the product

Conventional COLD STORAGES are made to store only one or two kinds of products as different products have different requirements and this reduces the efficiency of the COLD STORAGES. Our main aim is to design such a system which focuses on preserving many products in the same containment with utmost efficiency which will lead to preservation of more food products as well as ensure the food security in the times of need or a natural disaster.

Development of Cold Chain in rural areas presents the biggest challenge due to lack of existing infrastructure, poor financial strength of the farmers in taking part on an individual basis (high cost of services) and security issues. This can, however, be circumvented through the adoption of an Integrated Cluster Approach involving aggregation of villages in the form of clusters, which can be done in an effective manner wherein infrastructural facilities (such as that required for pre-cooling and pack houses in case of fruits and vegetables and bulk cooling in case of milk) can be provided in a pooled manner to the farmers.

II. CLASSIFICATION OF COLD STORAGES

As per the present day practice, the cold storages are classified as follows:

1. Bulk cold stores - Generally for storing single commodity, which mostly operate on a seasonal basis e.g. stores for potato, apple, chillies etc.
2. Multipurpose cold storages - These are designed for storing variety of products almost round the year. The products stored in this store are fruits, vegetables, dry fruits, spices etc. These units are mainly located near consuming centers.
3. Small cold storages with pre-cooling facilities for fresh fruits and vegetables, mainly for export oriented items

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like grapes etc. Most of these types of stores can be seen in the state of Maharashtra but the trend is now picking up in other states like Karnataka, Andhra, and Gujarat etc.

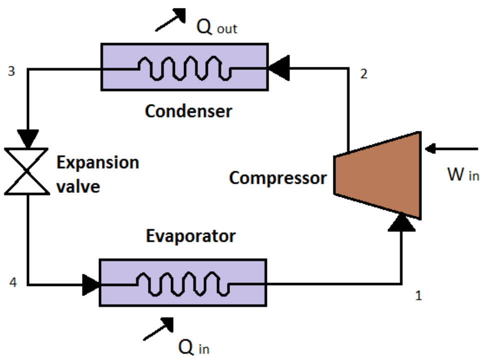
4. Frozen food stores with or without processing and freezing facility for fish, meat, poultry, dairy products and processed fruits and vegetables.
5. Walk-in cold stores located in hotels and restaurants, malls and supermarkets etc
6. Controlled atmosphere (CA) stores for certain Fruits / Vegetables like apples, pears, and cherries.
7. Ripening chambers mainly for banana and mangoes.

The target that we need can be achieved by improving the different prevailing refrigeration technologies. For this we need to get an overview of the refrigeration technologies used in INDIA.

III. OVERVIEW OF REFRIGERATION TECHNOLOGIES

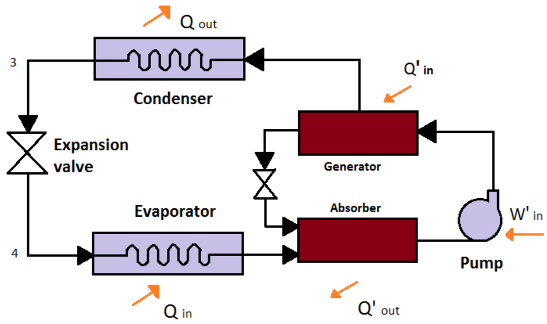
Vapour Compression System(VCS)

VCS are most commonly used in all refrigeration systems all over the world. Referring to the schematic diagram below, refrigerant enters the evaporator in the form of a cool, low-pressure mixture of liquid and vapours [4]. Heat is transferred from the relatively warm air or water to the refrigerant, causing the liquid refrigerant to boil. The resulting vapour [1] is then pumped from the evaporator by the compressor, which increases the pressure and temperature of the refrigerant vapour. The hot, high-pressure refrigerant vapour [2] leaving the compressor enters the condenser where heat is transferred to ambient air or water at a lower temperature. Inside the condenser, the refrigerant vapour condenses into a liquid. This liquid refrigerant [3] then flows to the expansion device, which creates a pressure drop that reduces the pressure of the refrigerant to that of the evaporator. At this low pressure, a small portion of the refrigerant boils (or flashes), cooling the remaining liquid refrigerant to the desired evaporator temperature. This cool mixture of liquid and vapour refrigerant [4] now travels to the evaporator to repeat the cycle.



Vapour Absorption Refrigeration System

Absorption refrigeration systems replace the compressor with a generator and an absorber. Refrigerant enters the evaporator in the form of a cool, low-pressure mixture of liquid and vapour (4). Heat is transferred from the relatively warm water to the refrigerant, causing the liquid refrigerant to boil. Using an analogy of the vapour compression cycle, the absorber acts like the suction side of the compressor-it draws in the refrigerant vapour (1) to mix with the absorbent. The pump acts like the compression process itself-it pushes the mixture of refrigerant and absorbent up to the high-pressure side of the system. The generator acts like the discharge of the compressor-it delivers the refrigerant vapour (2) to the rest of the system.



The refrigerant vapour (2) leaving the generator enters the condenser, where heat is transferred to water at a lower temperature, causing the refrigerant vapour to condense into a liquid.

This liquid refrigerant (3) then flows to the expansion device, which creates a pressure drop that reduces the pressure of the refrigerant to that of the evaporator. The resulting mixture of liquid and vapour refrigerant (4) is travel to the evaporator to repeat the cycle.

IV. OVERVIEW OF RENEWABLE ENERGY SYSTEMS

Biomass Gasifier System

Biomass gasification is thermo-chemical conversion of solid biomass into a combustible gas mixture (producer gas) through a partial combustion route with air supply restricted to less than that theoretically required for full combustion.

- Producer gas can be used as a fuel in place of diesel in suitable designed/adopted internal combustion (IC) engines coupled with generators for electricity generation.
- Producer gas can replace conventional forms of energy such as oil in many heating applications in the industry.

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- The gasification process renders use of biomass relatively clean and acceptable in environmental terms.
- Large monetary savings can accrue through even partial substitution of diesel in existing diesel generator sets.

Fuel is loaded into the reactor from the top. As the fuel moves down, it is subjected to drying and pyrolysis. Air is injected into the reactor in the oxidation zone, and through the partial combustion of 1 0 pyrolysis products and solid biomass, the temperature rises to 1100 oC. This helps in breaking down heavier hydrocarbons and tars. As these products move downwards, they enter the reduction zone where producer gas is formed by the action of carbon dioxide and water vapour on red-hot charcoal. The hot and dirty gas is passed through a system of coolers, cleaners, and filters before it is sent to engines. This gas even is used for direct combustion. In our case, we considered it as direct combustion to generate the heat required for VAM.

Solar Thermal System

Various devices for collecting solar radiation thermally have been devised. At the simplest level, a flat metal plate painted black and placed in the sun will heat up until it reaches a temperature where the heat that it loses to the air around it and also by radiating itself, exactly balances the amount of energy it receives from the sun. This "stagnation temperature" occurs at around 80 °C for a simple flat plate. If water, for example, is passed through passages in the plate, then it will stabilize at a lower temperature and the water will extract some of the energy in being usefully heated up. This is the essence of solar thermal energy collection. Greater levels of sophistication are aimed at reducing the amount of "thermal loss" from the collector surface at a given temperature. This allows energy to be collected more efficiently and at higher temperatures. Starting with flat plat collectors, there are different types of concentrating systems like parabolic troughs, parabolic dish, power tower etc.

V. METHODOLOGY

Procedures followed in determining the efficient system for cold storage:

I. Refrigeration cooling load
II. Resource availability(Solar & Biomass)
III. Calculate the overall efficiency assuming efficiency of individual parts
IV. Costing of each technology & land cost
V. Calculation of cooling generation cost (Rs/TR-Hour)
VI. Ranking of the technology

VI. REFRIGERATION COOLING LOAD

The refrigeration load is generally calculated for 24 hours period and covers the following:

i. Transmission load
ii. Load due to workmen
iii. Air change load
iv. Electrical lighting and motor load
v. Product load

The method of calculating the various loads is as follows:

6.2.1 Transmission load (Qt)

The transmission heat load gain through walls, roofs and floors can be determined by the following formula.

Qt kcal/day = Area (m2) × U factor (kcal/hr m2 ºC) × temp difference (ºC) × 24 hrs.

The temperature difference shall be the difference between the outside and inside design temperature plus the effect of solar gain on walls and roof.
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Table 3.1: Effect of solar gain on each wall

	East	South	West	Roof
Medium colour	3	2	3	8
Light colour	2	1	2	5

6.2.2 Load due to work men (Qw)

The people working in the cold stores dissipate heat at a rate depending on the temperature of the room but, usually, for a short period during the day.

Table 3.2: Typical amounts of heat generated by a person

Room temperature (ºC)	kcal/Hr per person
5	210
0	235
-20	340

6.2.3 Air change (Qa)

Air change load can be calculated by the following formula:

Qa (kcal/day) = Air quantity (kg/day) × (H1-H2)

Where H1 = Enthalpy of air at ambient condition in kcal/kg

H2= Enthalpy of air at inside temp in kcal/kg

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6.2.4 Electrical lighting and motor load (Qa + Qm)

The light levels vary between 2.5 W/m2 to 10 W/m2 in cold stores. The fan motors generate heat as per the energy inputs to the motors. Thus the cooling load can be calculated as follows:

Load for lighting (Q1) Qt (kcal/day) = Total watts × number of hours /day × 0.86

Additional load may be considered for the fork lift trucks etc. if operated inside the cold store. 2 0

Load of motors: Qm (kcal/day) = Total kW × heat generated per kW × number of hours/day.

6.2.5 PRODUCT LOAD (Qp)

The product load in case of a normal cold store can be calculated as follows:

Qp (kcal/day) = Product kg/day × specific heat × (Tp - Tf), Where Tp is the initial temperature and Tf is the final product temperature.

Generally the product cooling is assumed to be achieved within 24 hours.

Safety factor: A safety factor of 10 to 15% can be added on the refrigeration load to obtain the total refrigeration load.

An average solar gain effect of 2 ºC for walls and 5 ºC for exposed roof has been considered and added to the normal temperature difference.

6.3 RESOURCE AVAILABILITY

As per the available solar data for Pune city has been used for calculating refrigeration loads. For biomass, I had assumed that sufficient resource is available for running the refrigeration plant.

6.4 OVERALL EFFICIENCY OF THE SYSTEM

Here I had calculated the overall efficiency of the system by taking standard efficiency of the individual parts of the system. This can be said as the ratio of cooling output and energy input from renewable technology. OE takes into account both the performance of the whole system plus land utilization.

6.5 COOLING GENERATION COST (CGC):

This represents the price life cycle cost, expressed as a net present values, paid per Ton of Refrigeration (TR). Embedded in this figure are the costs of solar field, biomass gasifier, PV costs, cooling equipment, land, maintenance, installation and financing. In addition, this figure is based on the performance of each renewable technology and demand time series.

CGC [Rs. /TR] = Specific annual payments [Rs/Year TR] / Number of full load hours per yr = [_ + M] × capex + _ O / FLH

Where,

Capex is the capital cost (Rs. /TR cooling capacity)

_ is the ratio between the annual payments and the present worth of the capital investment.

M is the annual maintenance costs [% of the capex per year]

21_O is the annual operation cost [Rs. /TR of cooling capacity]

FLH is the utilizable cooling yield expressed as the number of full load hours per year [Hr/year].

6.6 COSTING OF THE INDIVIDUAL TECHNOLOGY AND LAND REQUIREMENT

Costing of the technology combinations has been done very approximately as collecting this information is quite a difficult task during my work. But managed to get approximate costs, most of these were obtained by receiving quotes from manufacturers and by talking to experts.

6.7 TECHNOLOGY COMBINATION CONSIDERED FOR COMPARISON:

6.7.1 Biomass gasifier (Direct firing) with dg support

In this option, biomass gasifier is used in producing the producer gas, which is directly fired to supply sufficient heat energy to the Ammonia Vapour Absorption Machine (AVAM) for generating 15 TR.

Assumptions:

a) COP of the AVAM has been assume 0.8

b) Calorific value of the producer gas is 1250 kcal/Nm3

c) Each kg of biomass used gives 2.5 Nm3

d) Diesel price is Rs. 45 per litre.

e) Full Load Hours (FLH) has been taken as 3060.

f) System operates for 340 days in a year.

g) Price of biomass fuel is considered Rs.2/- per kg.

6.7.2 Solar photovoltaic system with DG support

In this option, solar photovoltaic system is sized according to the power requirements of 100 MT the cold storage. We have not considered battery system for this system instead DG has been used for the night usage. Sizing of the PV system is done using RET Screen software. In all the options, 18 hours of operation of the refrigeration system has been assumed. I have taken 30.29 kWp as the total size of the SPV panels of moserbaer make. As per my calculations, total daily load is 180.4 kWh.

Assumptions:

a) DG is operated during the low or no sun shine hours during the day.

b) Local weather data is used for the calculation for the SPV system.

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6.7.3 Biomass gasifier (direct firing) and solar thermal system with SPV system as auxiliary power supply

In this option, biomass gasifier operates only 10 hours in a day and remaining heat energy is extracted from the solar thermal systems (Dish system). Each dish aperture area is 16 m2 and heat gain is 5 kWth. Remaining details are shown in the annexure at the end of the report. Our refrigeration effect required is 51.45 kW or 15 TR.

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Assumptions:
a) Standard infrastructure development costs have been used for the calculations.
b) Biomass fuel cost is Rs. 2 per kg.

6.7.4 Vapour compression system with electricity from the grid and with DG support

This is the conventional system where most of the cold storages in India are using. This is highly dependent on the electricity and requires uninterrupted supply. DG set is used as supplementary power supply during power outages.

Assumptions:
a) Cost of each unit of power from the grid is Rs.4.5.
b) Constant amount of products stored in the cold storage

6.7.5 Biomass gasifier (direct firing) with SPV system as auxiliary power supply

Here in this option, instead of using DG which is costly and pollutes the environment heavily, SPV system is used for all its auxiliary power requirements for running the pumps, lights in the cold store etc. Through this, the system can be considered as carbon neutral. The biggest challenge is securing the uninterrupted fuel supplies for the gasifier. Also relying on the SPV during low sun shine days is not a right option as the power generation from SPV will be lower during those days.
It is always better to have a DG set for uninterrupted supply of power. In terms of efficiency, biomass gasifier has almost 85 % of conversion efficiency and SPV has 11% of conversion efficiency.
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But the operation and maintenance costs of this gasifier would be higher. But the SPV has lowest maintenance as it does not have any moving parts. There will be battery bank replacement costs for every 5-6 years.

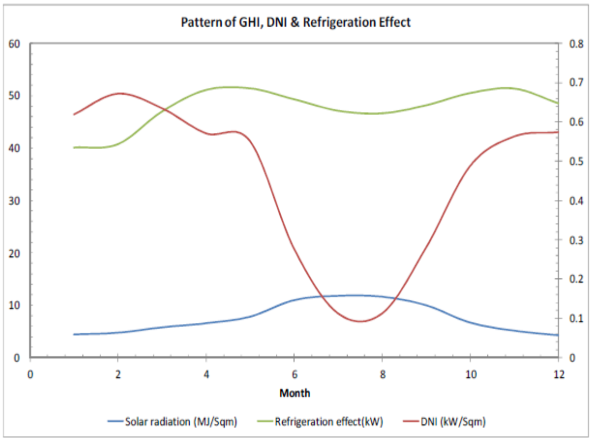
6.7.6 Vapour Compression System (VCS) powered by biomass gasifier coupled with gas engine

This system generates electricity at the site with the help of biomass gasifier (Power application). Here the producer gas generated from the gasifier is cleaned and then fed into the gas engine. Through this we can take the advantage of generating power at the site where getting grid electricity is a problem. The overall efficiency of this system is better than all previous options. General CoP of VCS is around 3.

VII. RESULTS AND DISCUSSIONS

7.1 REFRIGRATION LOADS AND TECHNOLOGY COMPARISON

Cooling loads has been calculated as per the methodology mentioned in the earlier section. The following graph shows the cooling demand over the entire year.



Cooling load and Energy Consumption of 100 MT Cold Storage

GHI, DNI and the refrigeration effect are closely related to each other. Refrigeration requirement is more during the hot days and the GHI and DNI is also usually more during these days. From the results and observation, it is understood that the biomass gasifier coupled with Gas engine with vapour compression system has the least CGC of Rs 37.88 per TR-H. However, the supply of biomass is a big challenge for this project. The overall efficiency is also very good for this kind system. In other options, Biomass gasification – solar thermal with ammonia VAM which is supported by SPV for auxiliary power requirements, the CGC is coming around Rs. 78.66 per TR-H.

But the initial costs are high in this system. During the day, if the DNI is not good then the performance will be below normal and need to run biomass gasifier for more hours which needs proper planning of the resources. We can have producer gas storage for a day if required. Still storage systems are not available for producer gas till now.
SPV-DG system is showing very high CGC of Rs. 80.72 compare to other options. The operating costs would be high because of diesel fuel. This is highly unreliable combination out of all other options. Non-concentrating technologies have poor overall efficiency, inspite of their good land utilizability and ability to use abundant summer diffuse irradiation.

As per my study till now, biomass gasifier coupled with Gas engine is the best option of all other options for doing the pilot project to test its performance in real situations.
In my study, out of all the options compared for the running the rural cold storage, Biomass gasifier coupled with Gas engine based vapour compression system found to be the best renewable energy technology option to consider for piloting. Apart from the initial costs and Cooling Generation Cost, this option has the environmental advantages too for using biomass as a fuel. Also it is easier to operate, not dependent on

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environmental factors and less dependency on electricity. Whereas, other options like biomass gasifier (Direct fired) with solar thermal and SPV-DG options are too costly to adopt at this moment.

This study is carried out considering various assumptions of the resources and cost of the system components. Due to this, this study can be considered as preliminary one and recommend to do the pilot project at any rural area with proper resource assessment, and then results should be ascertained. Also the subsidies have to be worked out for these new technologies to flourish..

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