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Performance analysis of cold storage with energy heat recovery wheel

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ABSTRACT

A cold storage is place where the various items such as vegetables fruits, medicines and potato etc. are stored to protect them from getting spoiled and to prolong their preservation period. This task is accomplished by storing the products at their preservation temperature and relative humidity etc. Preservation temperature for foodstuffs can be defined as the temperature at which its respiration rate would not harm the condition of foodstuffs in cold storage. Cold Storage required high electrical power consumption, therefore researchers is always trying to reduce the power consumption. In the present work an energy heat recovery wheel which is use to transfers heat from a warmer to cooler air streams has been utilized for energy saving in a cold storage and its detailed heat transfer and flow analysis has been carried out. A Potato cold-storage of capacity 5000 MT is taken for all analysis. It is observe that with the application of the heat recovery wheel the air infiltration/ventilation load is reduced from 10.724 % to 1.51 % and saving in running cost is observed as 25.5 % per day.

1. INTRODUCTION

Cold storage or refrigerated warehouses are facilities where perishable foodstuffs are handled and stores under controlled temperatures with the aim of maintaining quality. This task is accomplished by their storing the products at their preservation temperature and humidity etc. Preservation temperature for fruits can be defined as the temperature at which its respiration rate in Cold storage will not be harm materials as long as the cooling and warming is done in a controlled manner, with the moisture content of the components held stable. Effective and economic design of cold storage is an important requisite in business as ineffective design may lead to financial loss and in certain case may lead to unsafe operation of the system. Apart from the loss of capital due to degradation of quality of the products, there is also a loss of power and in the country like ours, it becomes of greater importance to save as much of power as possible.

The cold storages in following three main categories as listed below -
(i) Cold storages for storage of fresh horticulture products which do not require pre-cooling.
(ii) Multi-commodity Cold storages for short term and long-term storage of fresh horticulture products, which require pre-cooling and varying storage requirements.
(iii) Control Atmosphere (CA) Storages.

General recommendations about Pre-cooling:

For most fresh horticulture commodities, one hour time loss at the field temperature of 35°C between harvest and pre-cooling can reduce quality as much as 20 hrs. in storage under proper conditions. Delay in pre-cooling results in loss of moisture from the produce causes weight loss and combined with active micro-biological organisms result in deterioration of quality and value loss.

The design of the multi-commodity cold store facility and method of pre-cooling depends on various factors like nature of product, category and product type which determines the period of storage for example short term storage (generally refer to as 7 to 10 days storage) or long/medium term storage. Handling, stacking and storage methods, packaging, frequency of entry and exists are also key deciding factor.

(i). Fruits and vegetables which require on farm pre-cooling if transport time to reach them to cold storage is more than a few hours. It is desirable that fresh produce like grapes, mandarins, berries, cherries, leeches, melons, stone fruits, sapotas, okra, tomatoes, capsicum, chilli peppers, brinjal, cucumbers, green beans, peas, spinach should be cooled as rapidly as possible.

(ii). Less perishable fruits & vegetables such as mangoes, papaya, guava, green bananas, pomegranates, radish, cabbage, cauliflower and carrot can be transported from the field and pre-cooled at the cold storage facility.

2. Critical Storage conditions and Grouping of Products

Pre-cooling requirements vary based on produce and method of cooling such as room cool, hydro cool, forced air cooling, evaporative forced air cooling and ice packaging. However, forced air cooling within 4-6 hours is adoptable to a wider range of commodities than any other pre-cooling method and may suffice for most of the produce and therefore, it is taken for recommending general technical standards for pre-cooling system.

Basic Components of cold storage: The cold storage like every other refrigerating systems of the same magnitude employs the vapour compression method of mechanical refrigeration. Fig.1 presents main components of cold storage.

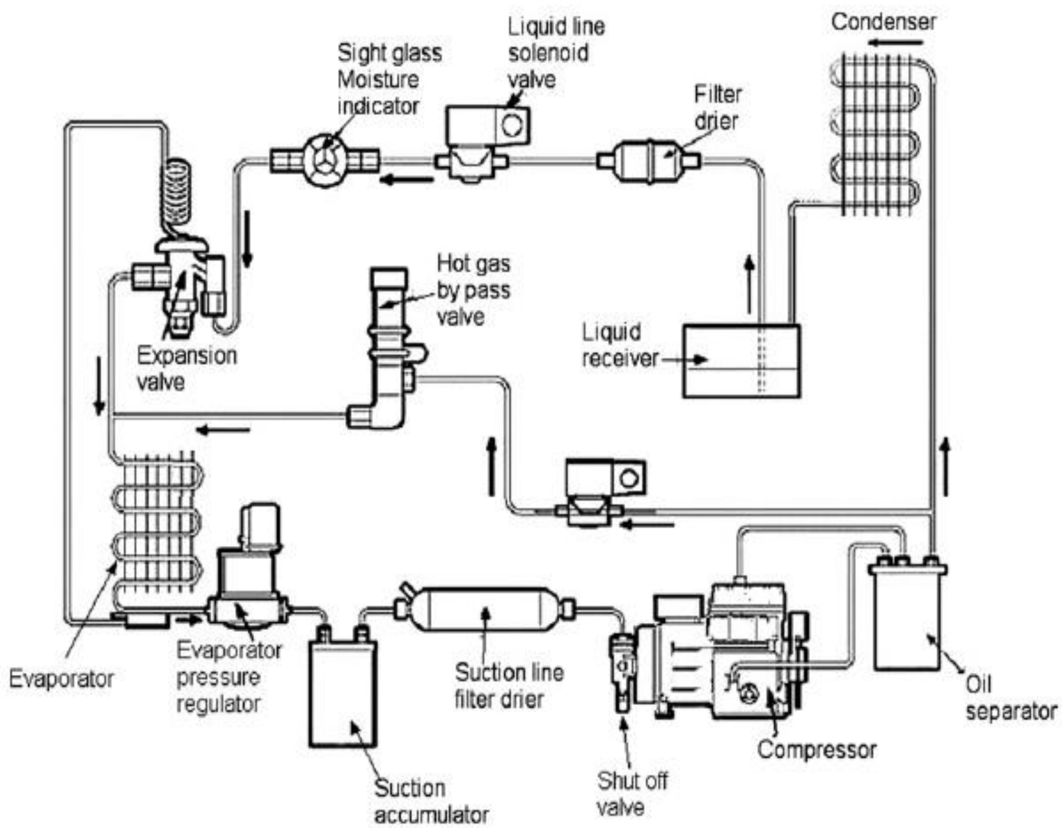

Fig. 1 Basic components of Cold Storage

Cold Storage for Potato: Potatoes are an important staple food crop and have a wide range of seasonal adaptability. It is a cool season crop and is moderately frost – tolerant. Temperature during the growing season has long been recognized as one of the most important factors influencing yield. As the population of the world is increasing day by day therefore food demand is increasing in the same order. In order to meet the flowing demand of food, its preservation is required. The consumption of potato in comparison to other vegetables in more therefore its preservation is required for long time therefore efficient food storage systems are required to preserve the food. World potato production has increased at an annual average rate of 4.5 percent over the last 10 years. Fig2 shows the commodity wise distribution of Cold Stores in India and it is clear from this figure that 78.3% of the cold storage is constructed for potato and rest for other products.

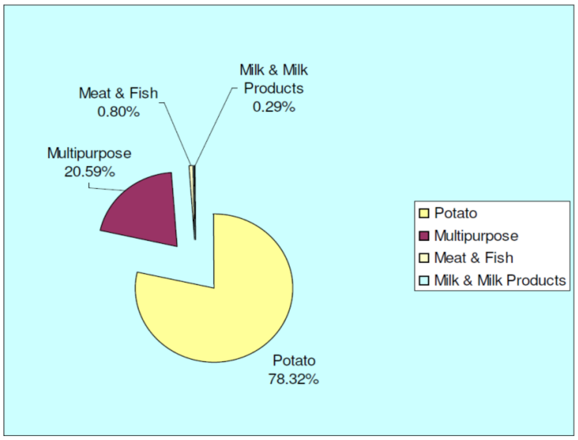

Fig.2: Commodity wise distribution of Cold Storage capacities in India

LITERATURE REVIEW: Cold storages are essential for extending the shelf life, period of marketing, avoiding glut, reducing transport bottlenecks during peak period of production and maintenance of quality of produce. The development of cold storage industry has therefore an important role to play in reducing the wastages of the perishable commodities and thus providing remunerative prices to the growers. It is seen that in India most of the cold storage is constructed for Potato therefore it is essential to construct the efficient cold storage for potato. Many researchers are working to improve the performance of the cold storage.

M. K. Chourasia and T.K. Goswami investigate airflow, heat transfer and moisture loss in a potato cold store of commercial scale under steady state condition using the computational fluid dynamics technique. They reported that the storage loss beyond permissible limit is one of the most important problems in Indian potato cold stores. The losses in the stored potatoes have a direct relation to the intricate coupled transport phenomena of heat, mass and momentum transfer therein. Also they have given that the temperature of the product is one of the most significant factors that govern the extent of storage losses and hence, the economic viability of the storage system. Moisture loss is an equally important parameter as product temperature, as the former affects the quality and quantity of the saleable product. It was found that in some of the stacks where the air distribution was comparatively poor, the relative humidity at steady state condition dropped by about 7% compared with the surrounding air.

M.K. Chourasia and T.K. Goswami investigate the effect of space between the storage bags and observe that gaping between the stacked bags of commodity has an important role over operation. They reported that increasing the porosity of the bulk medium reduced the product temperature and moisture loss during the cooling. They also observe that at a particular instant of time, the average temperature of the product and the total moisture loss showed an increasing trend with the rate of heat generation during the transient cooling. Steady state temperature of the product and the rate of moisture loss also increased while cool-down time and RH in the medium was found to decrease with the increased rate of heat generation. The moisture loss and RH in the bulk medium increased with the increase in skin mass transfer coefficient. It is also observed that the average temperature of the product dropped at a very fast rate during the initial cooling period of two days due to the high temperature gradient available between the product mass and the storage air. MANOJ KUMAR CHOURASIA suggested different aspects of design of cold storage and its improvement over the existing ones. Cold air flow being one of the key components in establishing the performance of a cold storage, a CFD analysis has been done and the results have been discussed in this paper. The problems generally encountered in running a cold storage have also been high-lighted and their probable solutions have also been suggested in this paper. **Mikal E. Saltveit** investigates the different parameters which affect the post-harvest parameters onto which the shelf life of the perishable foodstuffs depends. They have suggested the calculation of the amount of CO_2 generation in mg/kg/hr. at different temperatures. They also obtained that without a doubt, the most important factor affecting postharvest life is temperature. This is because temperature has a profound effect on the rates of biological reactions, e.g. Metabolism and respiration. Over the physiological range of most crops, i.e. 0 to 30 °C (32 to 86 °F), increased temperatures cause an exponential rise in respiration

Y H Yau In this paper it is reported that the hourly effects on heat recovery devices utilised in tropical HVAC systems were investigated empirically for the entire TMY year. They suggested that the redesigned heat recovery system had significantly enhanced the moisture removal capability and reduced the energy consumption of a HVAC system operating in the hospital environment. **Ephraim M. Sparrow, Jimmy C.K. Tong et al** carried out an experimental investigation to determine the operating performance of a rotating regenerative total energy wheel (TEW) and suggested that by using this wheel considerable amount of power consumption may be saved.

Zhuang Wu et al have developed a model of the regenerative heat wheel. They analysed the influence of variations in rotating speed of the wheel as well as other characteristics on dynamic responses. The numerical results have been compared with experimental measurements and with theoretical predications of energy efficiencies suggest the model-based analysis of a rotary regenerator to the development and implementation of mathematical models for the thermal analysis of the fluid and wheel matrix. The effect of heat conduction in the direction of the fluid flow is taken into account and the influence of variations in rotating speed of the wheel as well as other characteristics (ambient temperature, airflow and geometric size) on dynamic responses are analysed.

O.O. Abe et al proposed a new transient test method for air-to-air energy wheels. In this method the transient characteristics of several energy wheels exposed to separate and independent step changes in humidity and temperature are measured. Sensible and latent effectiveness, calculated from the new analytical model using these measured time constants, show agreement within uncertainty bounds with the effectivenesses obtained from standard steady state tests and with few exceptions, with the effectiveness calculated with a validated numerical model. Since the new test method is faster, more versatile (applicable for field testing and manufacturing plant quality control), requires less expensive equipment and\ is slightly more accurate than the standard steady state test method, it is expected to have wide applications. They reported that at same face velocity, the thicker the wheel, the larger the time constants.

Weiwei Liu et al suggested analysis of the desiccant wheel for outdoor air is and found that the temperature and humidity of outdoor air have great effects on energy consumption and COP for the suggested DOAS. The energy consumption increases with the rising of the temperature or humidity of outdoor air, and the COP goes up when the outdoor air temperature rises or the humidity decreases. Considering these effects, in order to keep steady indoor conditions, it is important to adjust the chillier in response to the change of outdoor conditions.

Based on the above literature it is seen that the power consumption of cold storage can be reduce up to certain level by providing the heat recovery wheel. In the present work a numerical the analysis of power consumption for 5000 MT potato cold storage proposing a energy recovery wheel has been done. The dimensions and other design criteria of cold storage were considered as per the guide line of National Horticulture Board [10].

ANALYSIS OF COLD STORE WITH SIMULATION OF ENERGY RECOVERY WHEEL

The Energy Recovery Cassette consists of a frame, wheel, wheel drive system and energy transfer segments. The segments rotate through counter flowing exhaust and outdoor air supply streams where they transfer heat and/or water vapour from the warm, moist air stream to the cooler and/or drier air stream. This energy recovery process can reduce cooling design loads by up to 4 tons per 1000 CFM of outdoor air ventilation while also reducing heating demand and humidification requirements. Energy recovery from the exhaust air is a simple process whenever there is controlled ventilation system. Two kinds of recovery ventilators exist; energy recovery ventilator (ERV) which transfers certain amount of water vapour (moisture) along with heat energy and heat recovery ventilator (HRV) which only exchanges heat energy between incoming and outgoing air streams. Recovery systems have two air streams provided by a supply and an exhaust fan. The supply and exhaust air streams are connected by means of an air-to-air heat exchanger which acts as a heat transfer system from warm air stream; indoor air, to cold air stream; outdoor fresh air without mixing them as shown in figure 3.

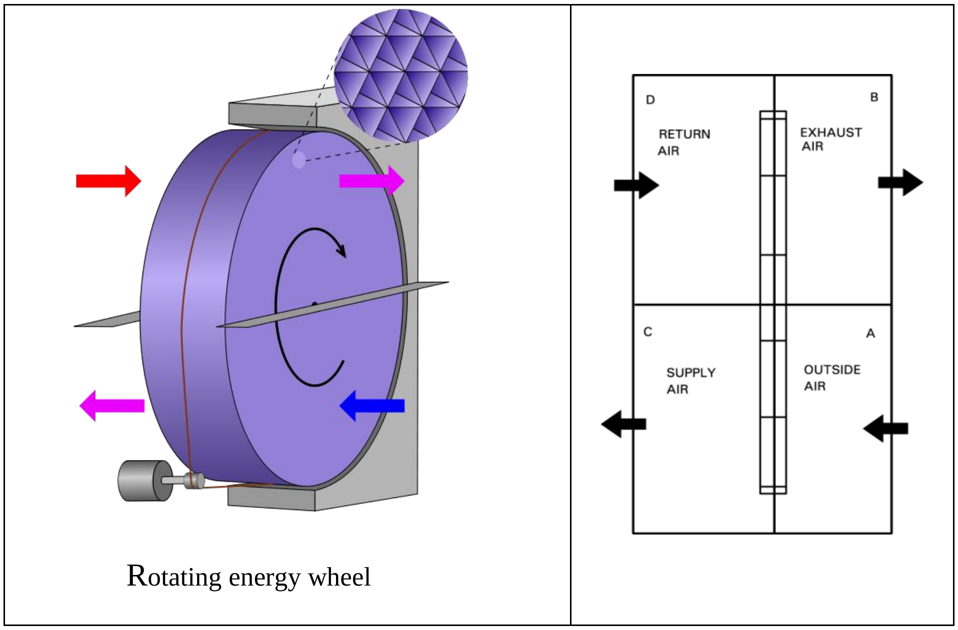

Fig 3 Working Principle of Energy recovery Wheel

Working of Energy Recovery Wheels**:** Air-exchange energy recovery wheels rotate between the incoming outdoor fresh air stream and the chamber exhaust air stream. As the wheel rotates, it transfers a percentage of the heat and moisture differential from one airstream to the other. Consequently, the outdoor air is 'pre-conditioned'. Rotary heat exchangers are also employed as a well proven and efficient means of heat recovery providing up to 80% energy savings. The rotating wheel (rotor) is made up of an air permeable heat transfer matrix which picks up heat from the exhaust air and releases it as the wheel passes through the cooler supply air. Depending on the air conditions and using desiccant coated rotors the heat recovery wheel can also transfer moisture providing both sensible and latent energy recovery savings result from the reduced need for mechanical heating or cooling

Types of Energy Recovery wheel:

There are two basic types of air-to-air energy recovery equipment-

(i) Sensible devices

(ii) enthalpy devices (or total energy devices)

Sensible devices transfer sensible energy (or heat) from the return air stream to the supply air stream. The heat raises the incoming outdoor air temperature in the winter and lowers it in the summer. Energy

Enthalpy devices transfer both sensible energy and moisture (latent energy) by using desiccants like silica gel.

Effectiveness of energy recovery wheel:

The primary key factors for evaluating the performance of rotary heat exchangers are temperature efficiency. They are defined as the ratio between the air condition change achievable by the rotary heat exchanger and the maximum possible condition change of the air. As per ASHRAE Standard 84 [11] the Air-To-Air Heat Exchangers effectiveness of energy recovery devices is defines as follows:

Temperature efficiency:

$$\varepsilon = \frac{Toa - Tsa}{Toa - Tra} \quad \text{(Cooling)} \qquad \varepsilon = \frac{Tsa - Toa}{Tra - Toa} \quad \text{(Heating)}$$

Where, Temperature in °C

Toa = Fresh air condition before heat exchanger (Outdoor),

Tsa = Supply air condition after heat exchanger (Indoor),

Tra = Extract air condition before heat exchanger (Indoor),

Tea = Exhaust air condition after heat exchanger (Outdoor)

Numerical analysis cold storage with energy recovery wheel using. For the present work a numerical the analysis of 5000 MT potato cold storage proposing a energy recovery wheel has been done using ANSYS 12.0[12]. The consideration of parameters for the analysis is as under:

Dimensions taken for wheels:

Outer diameter of wheel = 1200mm

Hub diameter = 200mm

Stream wise length = 200mm

The passage for air is to be made on the area around the hub which has 400 mm space radially. Following values of nodes and elements are created –
Type of element - rectangular
Relevance Center – Coarse
Active Bodies – 103
Nodes – 14547,
Elements – 10080

Results and Discussions: The detailed analysis of 5000 MT potato cold storage with energy recovery wheel was carried out and it is observe that the by using energy recovery wheel we can save significant amount of electrical power consumption during running period. The detail findings of analysis are as under:

1. Total refrigeration load for the pull down period of a potato cold store is calculated which is 408.6 KW further it is decreased to 373.43 KW when the energy recovery wheel apply between the air streams, consequently the incoming air from the ambient is slightly lower in temperature which results into less refrigeration load.
2. Electrical operating load are taken as there are various equipment involved in the system are selected according to the total heat load (refrigeration load); which sums to 125.35 KW. And by employing the recovery wheel the total heat load (refrigeration load) on the system is decreased the electrical operating load is also decreased which is calculated as 103.70 KW.
3. Decrease in electrical operating load leads to lessen the electrical power consumption from 2005.6 KWH/day to 1493.71 KWH/day when the wheel effect is taken into account.
4. As the power consumption is reduced the total electricity cost per day for running the plant is also reduced from 14,540.60/- to 10829.40/-. There is decrement in running cost of about 3700/-.
5. An improvement is coefficient of performance is observed as it rises to 3.587 from 3.26.

Figure 4 shows the heat load requirement for different cooling periods with and without recovery wheel.

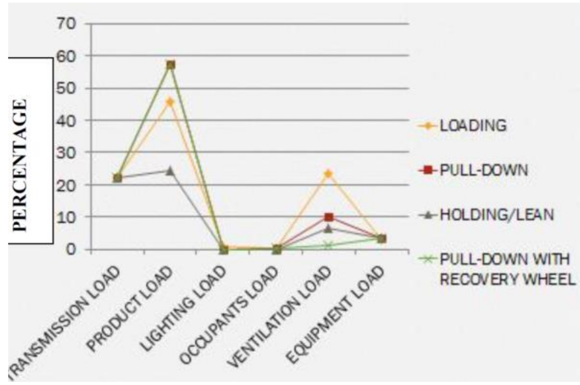

Fig. Heat Load requirement for different cooling periods with and without recovery wheel.

Conclusions:

1. In the present work a complete calculation of refrigeration heat load has been carried out for a chamber of 5000 MT.
2. In the present work the energy heat recovery wheel is employed for pull-down period of storing where the requirement of infiltrated air is around 4 to 6 air changes per day resulting in high heat load on the refrigeration system.
3. It is observed from the analysis that the air infiltration load / ventilation load is 1.509% of the total refrigeration load during pull-down period when heat recovery unit is applied for pre conditioning the air, and this ventilation load was 9.75 % of the total refrigeration load for the period without the use of heat recovery wheel.
4. It is also observed from the analysis that in case of cold storage without heat recovery wheel the storage temperature is to be reduced from 15 °C to 5 °C, whereas with heat recovery wheel the required reduction in storage temperature is from 10 °C to 5 °C, this reduces the power requirement for the pull down period.
5. Saving in the electricity per day is estimated to be about 3700/- based on the new commercial tariffs applied from 1st April 2014,which is 25.5% lesser than the earlier cost.
6. It shows that without heat recovery wheel COP of the plant is 3.259 which now became 3.587 after employing energy wheel.

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