Automation of Refrigeration Systems for Extending Shelf life of Fruits and Vegetables in Remote Areas for Economically Weaker Section

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Abstract

India is an agricultural country. During lockdown, there had been a big problem transporting the production to cold storages. Considering the problem of villagers, a low cost and affordable refrigeration system is proposed here. The time and cost of transportation through the cold chain and the storage are thus saved. This cold storage is automated to control the environmental conditions suitable for extending life of fruits and vegetables. It uses a microcontroller to control humidity, temperature and CO_2 level which is appropriate for the commodity to be stored by the farmer. It alerts the farmer before the expiry date of the stored commodity through a message on the phone number linked with the storage. It uses the water obtained from condensation on cooling ducts for humidity control. To maintain the optimum level of CO_2 inside the chamber, fresh air is circulated at regular intervals of time. It consumes same power as a refrigerator would consume. It does not require continuous water supply or ammonia as in regular cold storage systems. It can be easily customized for a particular user.

Keywords: automation system, refrigeration, remote areas, shelf life, microcontroller.

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1. Introduction

India suffers huge amount of loss due to lack of cold storage facilities near the agricultural lands. These losses increase when there is lack of transport facility. For good life of commodities a cold chain is required. The losses immediately after the harvest in the production of fruits and vegetables are approximately 6-18% (Nanda et al. 2012) [1]. Though fruits and vegetables are produced in such a large quantity, they are seasonal and are grown region wise in India .The demand of fruits and vegetables is thus not met and hence the market price becomes higher than usual. Thus good and numerous storage facilities are highly required. During lockdown, farmers faced big losses as the produced commodities could not be transported to cold storages.

Thus, this idea aims at providing a simple and economic refrigerated system which can be installed close to the fields at low installation and maintenance cost. The cost of storage is reduced through a big amount as no pre cooling is required. The cold chain transport cost is also saved. This cold storage chamber focuses on Indian farmers living in remote areas with poor transportation connectivity and illiteracy towards using smart phones. It aims to develop an economic, easy to use and install cold storage system, which automatically controls the atmosphere of the storage chamber. It also warns the farmer before the expiry duration of the commodity. Thus, an automation system is proposed which can effectively control the environmental conditions suitable to store a particular commodity.

At the time of installation the user needs to choose the commodity to be stored from the menu list. Once the user chooses the commodity, the microcontroller picks up the relevant required values of temperature, humidity and CO_2 level stored in the database. The real time values of these parameters are sensed by the sensors and fed to the microcontroller. The microcontroller then compares the values and accordingly acts on the relays connected to the compressor, spray, and the air circulation system. Thus the system maintains the environment suitable for extending the shelf life of the chosen commodity. The system can be easily customized for size, environmental conditions. As the air is circulated at regular intervals, it also takes care of ethylene level.

The smart and safe cold storage system controls the atmospheric factors of humidity, temperature and CO_2 level as required for the chosen or stored commodity. It has an arrangement of recycling water obtained due to cooling of coil. It is cost efficient, has nominal power consumption. The farmers can easily use it on mobile through GSM system provided. In case of situations when the expiry time of a commodity is nearby the same can be monitored through the camera. The precooling time as well as the cost of the same will be saved. Similarly the cost of transportation through a cold chain is not required. In case of unavailability of transport, it will save the commodities from getting damaged, specially its very useful in case of vegetables and fruit which have a very small life and get spoiled due to rain , high temperature etc . The storage capacity can be increase and decreased by increasing or decreasing the capacity of compressor. An Indian farmer who have do not use smart phone can easily use it. Fields of farmers which are located in areas which to not have well transport connectivity and are in remote areas will benefit from this design.

2. Literature review

In India, various storage methods are used in by farmers in different parts of India. A number of storage ideas have been evolved by the farmers which are installed at the field. Clamps, ventilated structures and evaporative cool chambers, cellars are few of them. These are the traditional methods innovated by our farmers. These are economical methods and can be easily built. With the evolution of technology, refrigeration technology is now being used. The commodity is transferred through cold chain to the cold storages, where it is stored at low temperatures. Commodities which get spoilt due to moisture are pre cooled to temperatures lower than room temperature to remove extra moisture. But the storage of fruits and vegetables require specific conditions of relative humidity, temperature and CO_2 level. There is an urgent need to develop modern storages for fruits and vegetables as they have a very short lifetime. The problem of tomatoes and onions getting spoilt in big amounts is quiet popular in our country [2]. Considering the societal needs of our country, it’s essential to build low cost smart storages which can fulfill the purpose as well as is economical too. In 2011, Z. Xu and Y. Wang designed a system to monitor the temperature of cold storage. This is a monitoring system which monitors the temperature at different points of refrigeration system. In 2013, R. A. Verzijlbergh and Z. Lukszo gave a model of cold storage which has a photovoltaic energy generation [3]. In 2020, K. Umamaheswari, M. Susneha and B. S. Kala proposed a Smart Cold Storage System which is specifically designed for Stock Management with better efficiency. It utilized the technology of supply chain management and internet of things for collecting and processing data [4]. R. Pedersen et al. in 2013, proposed the mechanism of controlling the refrigeration system attached to a smart grid [5]. Srinivasan, S. has worked on the analysis of automatic air conditioning system by using support vector machine. Joybari, M.M.in 2015 proposed the materials which can change their phases on materials, Haghighat, F., Moffat, J. and Sra, P 2015. Heat and cold storage using phase change materials in domestic refrigeration systems for providing both hot and cold storage systems. Zhai, X.Q. reviewed the functioning of phase change in refrigeration system. Jia, X. proposed periodical SO2 fumigation for improving the quality of ginger storage. Tabatabaeipour, S and his colleges have worked on fault detection due to wrong sensor assignment in supermarket refrigeration systems in 2009. Reindl, D.T. and Denkmann, J.L. proposed automatic purgers for the refrigeration systems. Rasmussen proposed an automatic tuner for controlling the superheat in a refrigeration system. Xiao-yan in 2011 has tested the performance of a compressor in an automated system. In 2007, Abdulateef, J.M. proposed a solar absorption system. Apart from different types of refrigeration systems, many researchers have proposed use of different chemicals in the refrigeration system and during packaging to increase the shelf life of fruits and vegetables[21-33]. A chemical treatment is given which retards ripening and retains the freshness post harvest. Ethylene is used to ripe bananas while apples give off ethylene. Thus, when different commodities are stored together, they may affect the freshness of the other. Professor Adel Kadel at University of California- Davis observed that some Olefins other than ethylene form bond at ethylene receptors in plants and block the action of ethylene. 1-methylcyclo-propene (MCP) is one such olefin which can be used for retarding the ripening process. But it is harmful for consuming. It has not been approved to be used for eatables though it has been widely used in retarding ripening of flowers.

3. Atmospheric conditions for storage of commodities

Various commodities require various atmospheric conditions for storage Commodity Storage. In the case of fruits and vegetables, various factors such as temperature, relative humidity, presence of CO_2, ethylene, air circulation, light etc are of importance. These factors, when controlled, can keep the commodities safe for a longer duration. The national horticulture board of India has defined specific technical standards for various commodities. The World food logistic organization has come up with a manual for commodity storage. The variation or the tolerance of each atmospheric parameter is defined. The temperature can have a variation of not more than $\pm$ 1°C of the temperature recommended for a commodity. Similarly, the relative humidity (RH) required can vary in the range of from 95% to 98% RH for case of fresh fruits and vegetables like grapes, kiwi fruit, carrots, cabbage etc and lower in the range of 65% - 75% RH in case of onion and garlic. The level of carbon dioxide must not exceed 4000 PPM when the commodity is loaded and 2000 PPM when stored. To maintain the CO2 level of less than 4000 ppm, 2 to 6 air changes per day are required. The commodities should be stored in the dark to slow the metabolism. As per storage standards, all the storage commodities are divided into six groups as per the requirements of storage atmospheric conditions, for example, tomatoes fall in Group 6. For these commodities, the storage temperature required is 13 to 15°C and the RH value should be 85-90%. Storage of Commodities like onion and garlic require de-humidification. In case of dried roots, bulbs, dry fruits, nuts, low humidity needs to be maintained [6]. To achieve the same, the commodities are first cooled much below the room temperature. This removes extra moisture. After the excess moisture is removed, the commodities are stored at the desired storage temperature. For the storage of fruits like bananas and apples, the modification of CO2 and O2 levels yield good results. Shreyas et al. have developed a monitoring system which requires a web server for monitoring [7]. On the basis of incompatibility with temperature, the commodities are classified into three categories. Commodities like onion, grape, apple and carrot are not sensitive to temperature between 0°C to 4°C are categorized as most perishable products. Tomato, potato, mango and orange are little sensitive to 4°C to 8°C. Lady finger, banana, pineapple and pumpkin are sensitive to temperature above 8°C.

4. Technology

The smart cold storage system uses a very simple technology. The farmer only requires a simple mobile phone to get the updates. He does not require knowledge of using a smart phone or web application. The cold storage chamber designed along with the automation system using a GSM module. The farmer gets a text message and an image of the commodity stored before the expiry date. The main focus of developing the chamber is easy installation near the fields. It is economical and save both time and money of the transportation and cold storage. It's simple to be used by a farmer who does not use a smart phone. A small scale cold storage chamber is designed using R134A refrigerant instead of using Ammonia which is used in cold storages. Ammonia is dangerous and hence requires lot of safety arrangements. R134a is also known as Tetrafluoroethane (CF_3CH_2F). This refrigerant

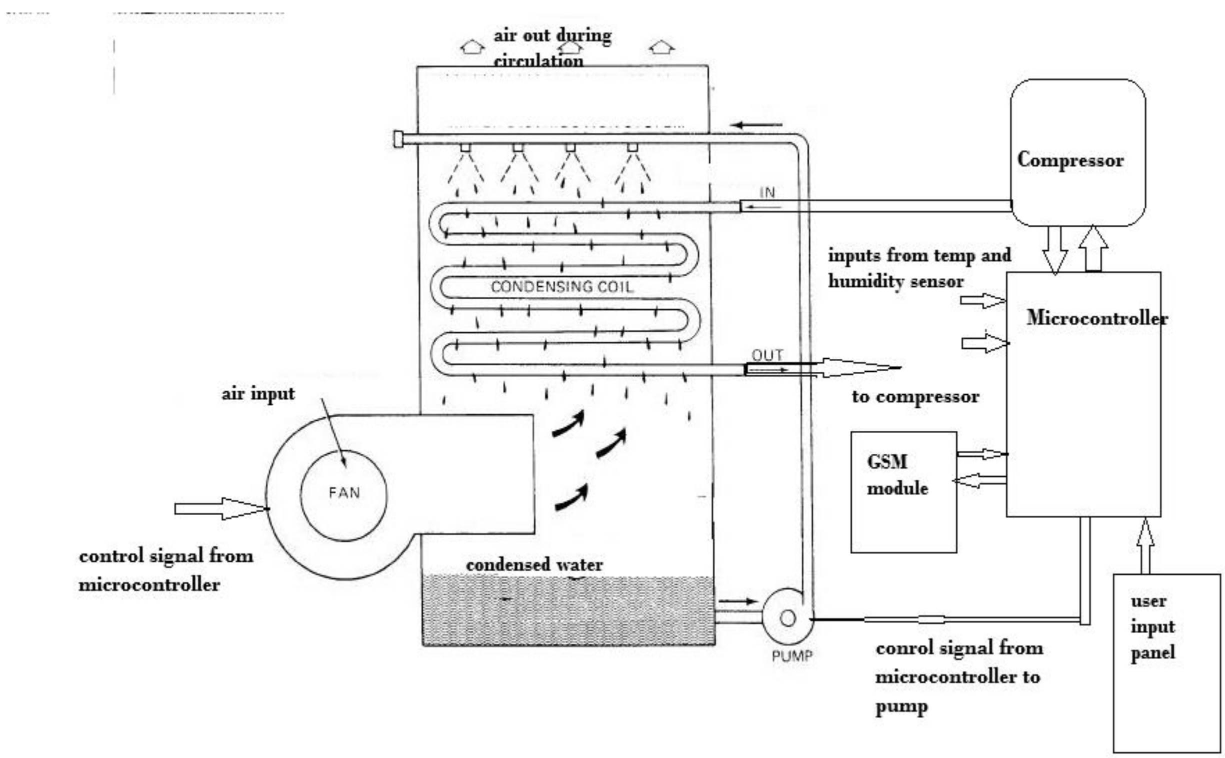


Figure 1: Automated environmental control refrigeration system.

is harmless and thus needs no extra safety arrangements as compared to ammonia which is generally used in cold storages. A galvanized steel sheet of 0.5mm, commonly known as GS sheet is used to make the walls and ceiling of the storage chamber. The wooden pegs are inserted at regular intervals. A polythene sheet of 250 microns is used on the floor, which works as a barrier to water vapors. The automation system uses a humidity and temperature sensor, DTH11. It uses an R-pi microcontroller along with a GSM module. The GSM module is used to keep the system connected with a user's phone which has a relevant application. The user can thus monitor and control the system functioning. An Rpi camera and a LED module are also provided inside the chamber, which can be used to get the picture inside the chamber, if required. The carbon dioxide level is sensed by the CO_2 sensor, MG811. The temperature control is achieved using a digital thermostat. The CO_2 level is controlled by providing a vent for circulation of air, which opens if the CO_2 level goes beyond the required values or id the humidity is high. In case of low humidity, a spray is used which produces mist in air. A thermostat is used to control the temperature. A water spray is used to moist the air if the humidity sensed is lower than required for storage.

Figure 1 shows the set up entire automated environmental control refrigeration system. The condenser normally works as an air cooled condenser but it works as an evaporative condenser whenever the spray is "ON". Thus, it can be used in places with scarcity of water. It's cheaper than a water cooled condenser as it does not require a separate cooling tower. The water used her forms a closed loop as the condensed water collects in the

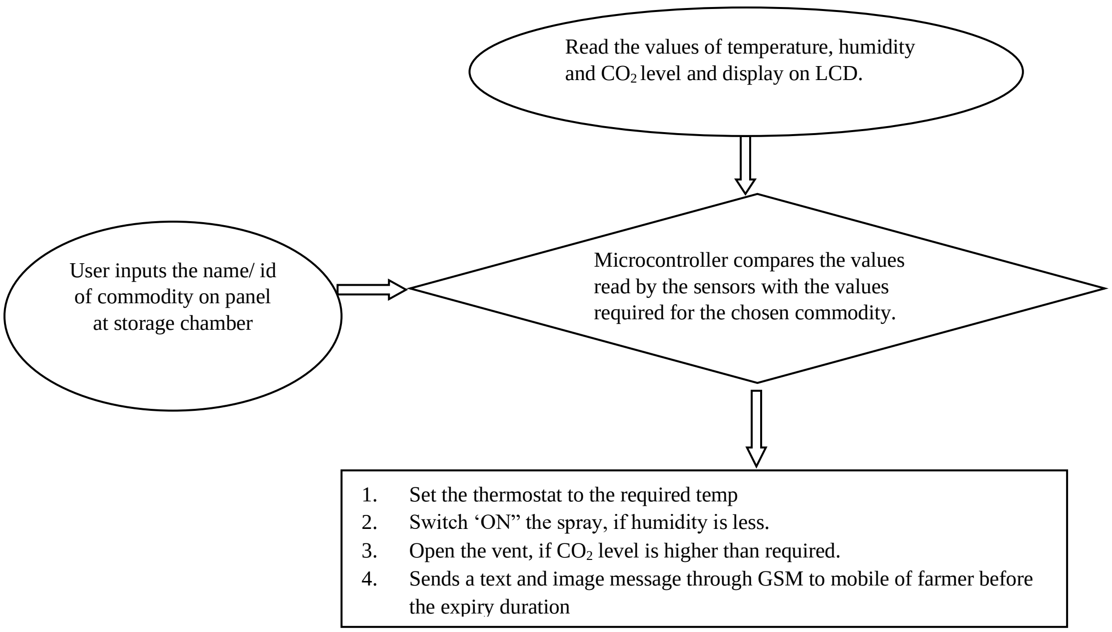


Figure 2: Flow for control of atmospheric parameters for cold storage

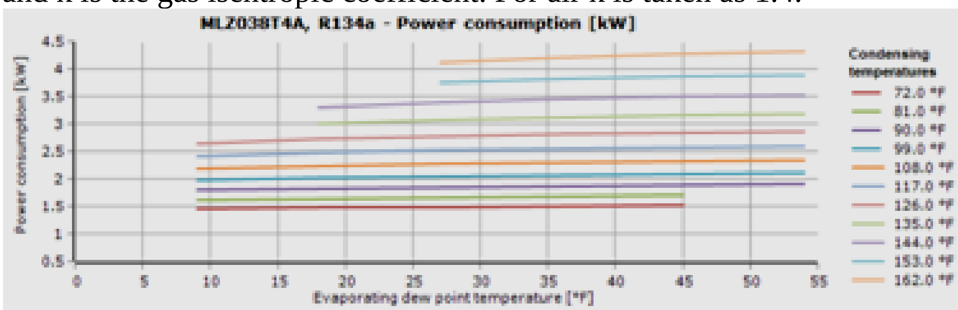
water tank at bottom and circulated back for increasing humidity whenever required. The water consumption is very low. Another simple form of condenser used normally in older type cold storages is called as atmospheric condenser. The principle of the atmospheric condenser is similar to evaporative condenser, with a difference that the air flow over the condenser takes place by natural means as no fans or blowers are used. Whenever the humidity is sufficient inside the chamber, the system works as air cooled condenser. But, whenever the humidity falls below the required level, the spray system turns "ON" and sprays the water over the coil. In this situation the condenser works in evaporative phase. The microcontroller is fed with the program for automation and controlling values of temperature, humidity and CO_2. The flow diagram of the automation algorithm is given in Figure 2.

5. Implementation and Results:

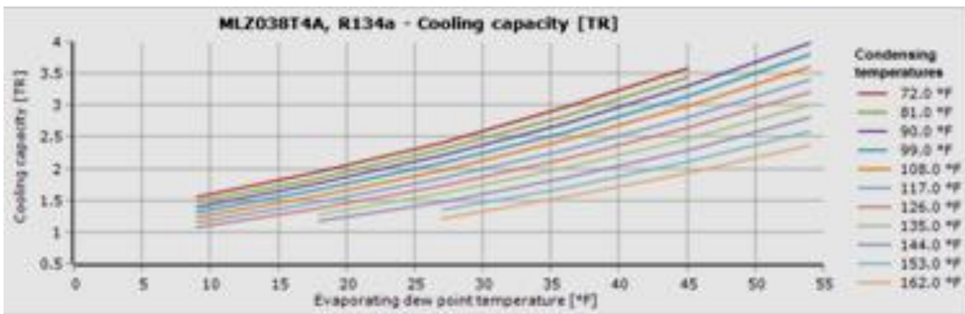
The cooling system was analyzed on Cool selecter 2, open access software. The compressor capacity was taken as 2TR. The evaporation temperature is and condensation ambient temperatures are taken as 21°F and 71.6°F. The performance of the reciprocating compressor and condensing units has been analyzed. The variation of the parameters of power consumption in kW, current drawn in Amperes and the Cooling Capacity in TR have been studied with respect to the variation in Evaporating dew point temperature in Fahrenheit. The six graphs in Figure 4 show these variations at various condensing temperatures from 72°F to 162°F. The evaporation temperature is 5°C less than the temperature of cold water at outlet. The condensation temperature is chosen 5°C more than temperature of cold water at outlet and is 10°C to 15°C more than the ambient temperature. For a single stage gas compressor, the power of isentropic compression P_{is} is given by the following expression.

$$P_{is} = 2.31*(T_{dis}-T_{suct})*(k/(k-1))/M*Q_m$$

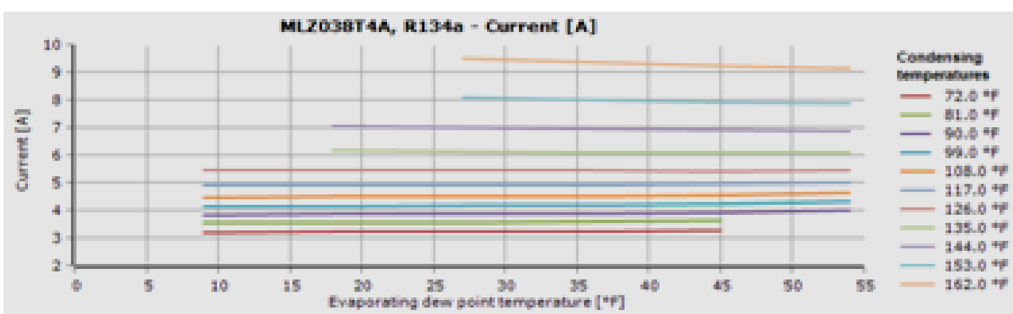
P_{is} is the power in kW, T_{suct} is the temperature at the inlet of compressor in Kelvin, $T_{discharge}$ is the temperature at the outlet of compressor in Kelvin, M is the molar weight of refrigerant gas in g/mol, Q_m is the throughput of the compressor in t/h and k is the gas isentropic coefficient. For air k is taken as 1.4.



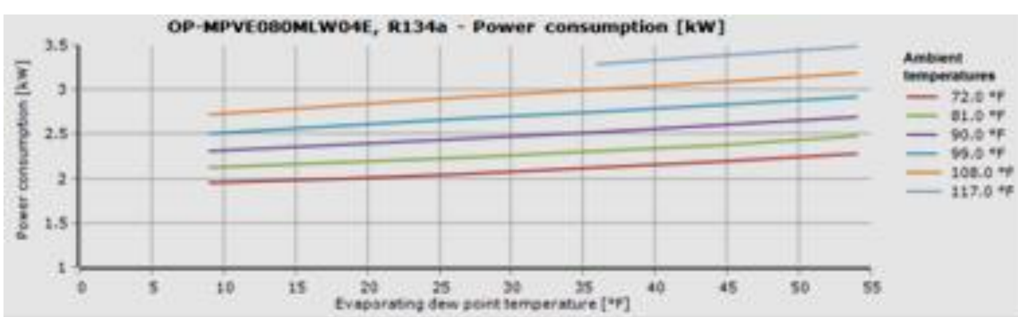
(a) Variation of power consumption (kW) with respect to evaporating dew point temp [°F] for compressor



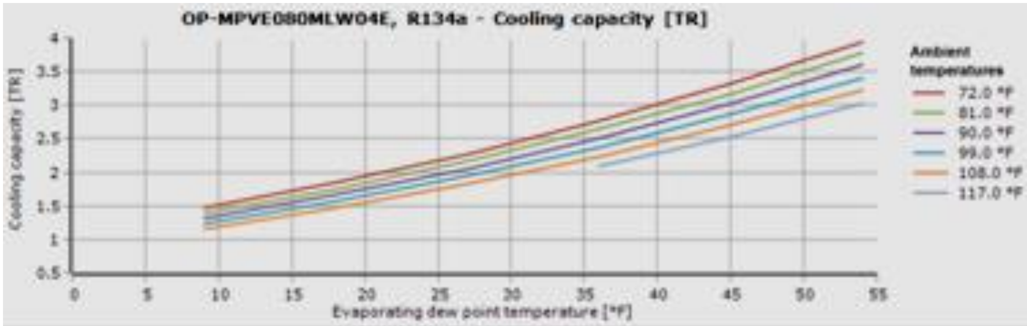
(b) Variation of cooling capacity [TR] with respect to evaporating dew point temp [°F] for compressor



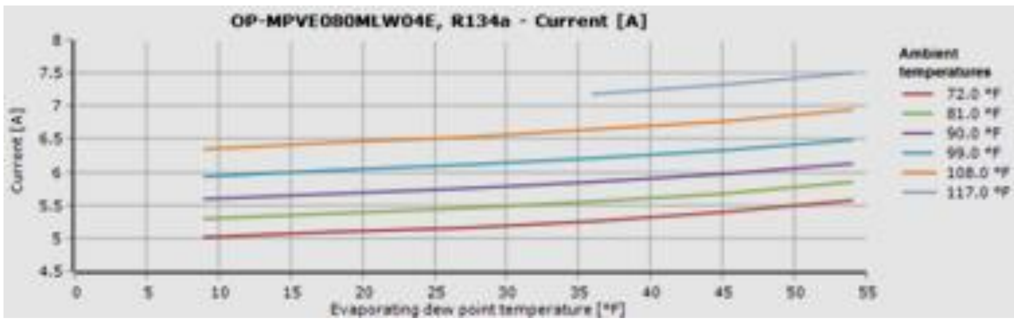
(c) Variation of Current drawn (A) with respect to evaporating dew point temp [°F] for compressor



(c) Variation of power consumption (kW) with respect to evaporating dew point temp [°F] for condensing unit



(d) Variation of cooling capacity [TR] with respect to evaporating dew point temp [°F] for condensing unit



(e) Variation of Current drawn (A) with respect to evaporating dew point temp [°F] for condensing unit

Figure 4: Performance analysis of compressor and condensing unit

The performances of the compressor and condensing unit have been analyzed for power consumption, cooling capacity and current utilized with respect to evaporating dew point temperature. The graphs in figure 4 have been obtained for a cooling capacity of 2TR. The values of evaporating temperature and condensation temperatures are chosen to be 21°F and 71.6 °F. The refrigerant used is R134a. The observations are taken for a range of condensation temperatures ranging from 72°F to 162°F. The graphs in Figures 4(a), 4(b), 4(c) obtained for the compressor show that the average power consumption of the compressor at 72°F is 1.5kW for the entire range of evaporating dew point temperatures. The cooling capacity observed from the plots ranges from 1.57TR to 3.57TR. The current drawn is always below 10 Amperes. At Graphs obtained for condensing unit are shown in figures 4(d), 4(e), 4(g) show that at 72°F, the power consumption ranges from 2kW to 2.25kW approximately, the cooling capacity ranges from 1.5TR to 4TR and the current drawn is approximately 5 Amperes. For tomatoes and onions, the standard storage conditions as prescribed were used and the prototype was tested for onions and tomatoes. Table 1 shows the results showing the storage life achieved or the total shelf life achieved under the specified environmental conditions of temperature and humidity. The CO_2 level is maintained below 4000 ppm. The commodities are stored in dark.

Table 1: The storage life under various conditions

Commodity	Shelf life in air	Humidity (RH) in %	Temperature (°F)	Standard Storage life in controlled environment(weeks)	Storage life achieved by the prototype (weeks)
Onions	6 weeks	65-75	32-36	32	25
Mature Green Tomatoes	5 days	85-90	65-70	4.5	2.5

The table shows that the shelf life of onions and tomatoes increased considerably as compared to the shelf life when stored in open air. Though the improvements can be done to increase the storage life and reach the standards of a proper cold storage system.

6. Limitations

This design has few limitations. It needs a continuous power supply. Separate chambers for each commodity will be required depending upon the requirements of atmospheric conditions. Though, in general a farmer produces only single commodity in big quantities, so this situation may be applicable to fewer cases.

7. Future recommendations

The power efficiency of the system can be increased by using a photovoltaic system. In most of the fields solar energy is available in abundance. The cooling efficiency can be improved by placing the storage system as an underground storage and using the hydrogen balls inside the wall structure. An image processing system can be installed with the camera to identify the status of the stored vegetables, fruits etc and send a warning to the user in case of some unusual harm to the system. An interactive text message system compatible with simple mobile phones can be built which will give an additional advantage of getting the picture of the commodity as and when required.

Conflict of interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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