Performance Analysis of Cold Storage for the Different Stacking Arrangements

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Abstract— The present work is to investigate the effect of the different stacking arrangements on the performance of the cold storage. To analyze performance of the cold storage, an experiment is carried out in which the temperature distribution within the cold storage and power consumption in the different stacking arrangement are kept under observation. The temperature inside the chamber is a crucial parameter on which whole performance of cold storage depends. Various arrangement of stacking is accomplished by the changing the gap between the columns of stack. The experiment is carried out for the three arrangements with gap between the columns of stack of 10cm, 20cm and 30cm. For better temperature distribution within the cold storage, good air circulation inside the cold storage is desirable. And it is also done by the changing arrangement of stacking. Therefore, the optimization of temperature within the cold storage is carried out in different stacking arrangement and resulting in improving the performance of cold storage.

Keywords— Stacking Arrangements; Performance of Cold Storage; Temperature Distribution; Power Consumption; Optimization; Cold Storage

1. INTRODUCTION

In order to reduce deterioration, products are kept on the low temperature. Low temperature to the product is done by cooling in the cold storage, the storage temperature and other desired parameters like relative humidity are maintained. For the preservation of products, control of temperature and relative humidity are the critical parameters because the unexpected amount of these can contribute in the breakdown of the products. Temperature rise to the product increases the rate of deterioration. The most of chemical reaction including the deterioration will be double on each rise in temperature of 10^{O}C. On the other side, higher relative humidity contribute the moisture enough to support detrimental chemical reaction in the product and, in addition with high temperature, the mold growth as well as insect activity will be raised.

There are three different methods of keeping the products in storage namely bulk storage, storage in crates and storage in gunny bags (Ooster, 1999) [1]. Here, storage in crates is employed in which the product is kept into the plastic crates and arranged in stack on the wooden pallets having regular gaps for air circulation. The existing arrangement of the stacks within the cold store is one of the reasons behind heavy storage losses (Chourasia & Goswami, 2001) [2]. To reduce the storage loss, refrigeration system is applied to cold chamber where cold air from evaporator flows through crates thereby removing the heat of product. The crates should be so stacked that air flow can approach each individual crates for adequate and rapid cooling. It is necessary that the crates should so arranged that air channels can be made for direct air movement. There should be some gap between the crates and walls to enable refrigerated air to absorb the heat of conduct through the walls. To regulate uniform air flow within the cold storage, VFD and fan are installed to get higher efficiency.

The research objective of this paper is to experimentally analysis of performance of cold storage for the different stacking arrangements. The temperature is only parameter on which whole performance of cold storage depends. In this paper we studied experimental analysis of the temperature distribution with respect to running hour of cold storage for the different arrangements of stacks to reduce the storage loss within permissible limits.

Some studies on various parameters of cold storage are found that made contribution in analysis of performance of cold storage. Burton et al. (1955) [3] made study for the effect of stack dimensions over the temperature of the potatoes in unventilated stacks. Stewart and Dona (1988) [4] simulated natural convection heat transfer inside a grain bin and developed streamlines and isotherm patterns for different cylinder height to radius ratios. Chourasia et al. (1999) [5] modelled the effect of aspect ratio and volume of the bag on temperature profile in a single bag of potato during the cold storage. M.K Choursia and T.K. Goswami(2007) [6] studied and s investaged the air flow, heat transfer and moisture loss in commercial potato cold store through steady state CFD modeling.M.K. Chourasiya, T.K. Goswami(2007) [7] Studied the effect of stack dimensions and stock volume as well as gaps between and within bagged potato in the stack on cold down time of the product using CFD. Van Gerwen and Van Oort [8] utilized the Phoenics CFD package to determine air velocities and product temperature based on cooler airflow rate, product properties and the geometry of cold store and stowage pattern. In this model, the authors gave design recommendations in order to better homogenize airflow circulation and temperature levels in the load. Talbot, Oliver, and Gaffney [9] studied that the variations of the porosity inside the carton affect the predicted temperature of the product. Son H. Ho, Luis Rosario, Muhammad M. Rahman(2010) [10] studied the numerical solutions of steady state airflow and heat transfer for three-dimensional and two-dimensional model of refrigerated space in which a set of cooling coil unit is installed in front of the arrays of stack of palletized product packages.

2. EXPERIMENTAL SETUP

The performance of cold storage only depends on the temperature. Lower the temperature inside the cold chamber, greater will be the performance. To achieve the low temperature to storage, a refrigeration system is employed. This refrigeration system works on vapor compression. The refrigerant R-22 is used as working fluid for vapor compression refrigeration.

2.1 Components of Cold Storage

The experiment setup of cold storage consists of following components:

- Compressor
- Condenser
- Receiver
- Filter-Drier
- Solenoid valve
- Evaporator
- Fans

Compressor: Reciprocating or screw type compressors are generally used in the cold storage. The reciprocating and screw compressors are best suited for use with refrigerants which require a relatively small displacement and condense at relatively high pressure, such as R-12, R-22, Ammonia, etc.. Compressor in experimental setup is of Emerson Climate Model CR36K6 reciprocating type. Its rated refrigeration capacity is 8.739KW. Evaporator/condenser temperature is 43.3/54.4℃ . The rated electric consumption is 2.86KW.

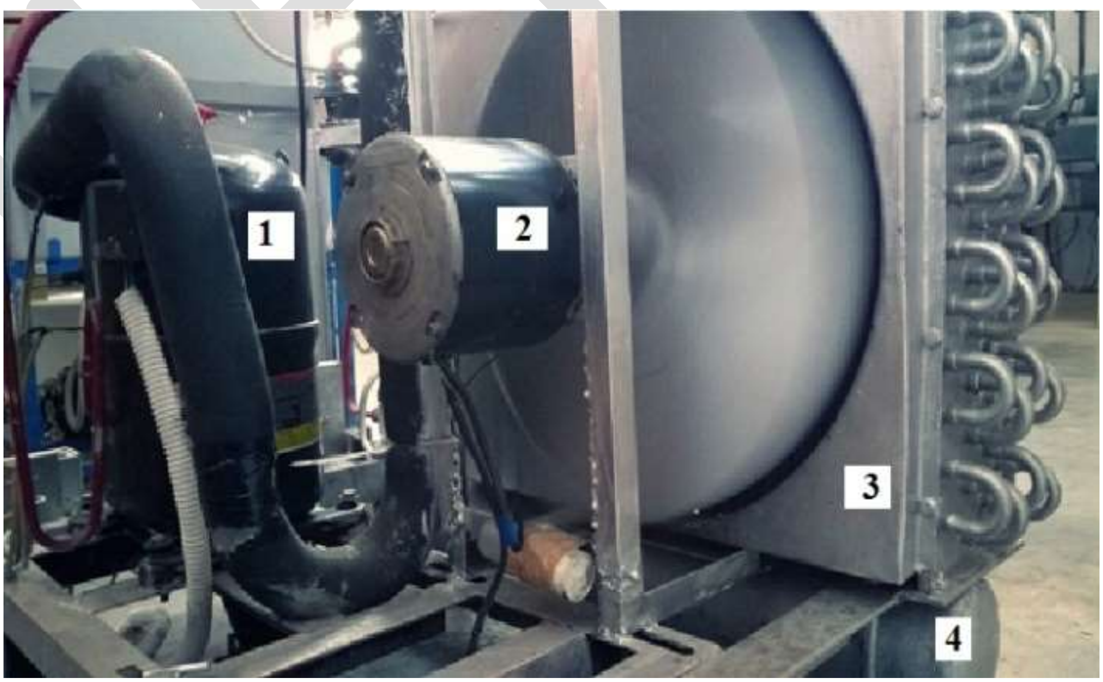

Figure 1 Various Components of Cold Storage: 1. Compressor, 2. Fan, 3.Condenser and 4. Receiver

Condenser: It is an essential part of the cold storage plant. It is applied to work at higher side at the constant pressure. Three types of condenser are frequently used in the cold storage – atmospheric or air type, water cooled and evaporative condenser. In the experiment set up, forced air cooled condenser of 4.5TR is used. It consists of 48 Al tubes of length 60cm and 1.5cm in diameter. The fan used to force air has specification of 920 RPM, 187 W power rating. For more heat transfer, Al fins are employed in condenser with a regular gap of 2mm.

Receiver: It is basically storage vessel designed to hold excessive amount of refrigerant not in circulation. Refrigeration systems used to varying heat loads, or systems using a condenser flooding valve to maintain a minimum head pressure during low ambient temperatures, will require a receiver to store excess refrigerant. Liquid receivers are employed at liquid line as near as to the outlet of condenser. The piping between condenser and receiver should be so arranged that it can enable for free drainage. A receiver's storage capacity is based on 80 percent of its internal volume at a refrigerant temperature of 90°F as per ARI Standard 495. Generally, a receiver is selected to receive 90 percent of the total system charge to provide adequate reservoir during high loads and to allow the refrigerant to be isolated between the condenser and the receiver during repairs.

Filter-Drier: A filter drier in refrigeration system has two essential functions: first, to absorb contaminations present in the system, such as water, which can create acid and second function, to provide filtration. The functions of filter dried are accomplished by use of desiccants within filter drier. The three most frequently used desiccants are molecular sieve, silica gel and activated alumina.

Solenoid valve: A solenoid valve is an electromechanical valve often used to control the flow of liquid or gas. Solenoid valves are widely used in many applications and are commonly used in refrigeration and air conditioning systems. Its function is simply to turn refrigerant flow on and off. Solenoid valves provide fast and safe switching, reliability and compact design. A solenoid valve of CASTEL ITALY type HM2 is used in experiment. The voltage range and rated power capacity are 220-230V and 8W, respectively.

Evaporators: It is also called cooling coil of the cold storage units. It plays a vital role in cooling the cold chamber and applied at low pressure side and pressure should be uniform throughout the cooling process in the refrigeration units. The refrigerant of liquid type from solenoid valve is passed down to a low pressure liquid and passed on to an evaporator mounted on cold store wall from solenoid valve is admitted to the evaporator as shown in *figure 2* and then there, the liquid refrigerant starts absorbing the heat from ambient medium thereafter it boils and then converted into the vapor phase.

Figure 2 Ceiling Mounted Cooling Coil inside Cold Chamber

The temperature of boiling refrigerant in evaporator must always be less than that of ambient medium so that heat absorption can be there by the refrigerant. The dry expansion type of evaporator is being used to cooling the chamber of the cold storage unit and mount to wall of cold store. The evaporator used in cold storage has specification of 32 Al tubes length of 66cm and 2cm in diameter. The rated capacity of evaporator is 3 TON. The fan used in evaporator to forced air has 920 RPM and 187W rated power capacity.

Fan: In order to save power in the part load operation periods, fan works on cycled operations. Variable frequency drives are used on the fans to save power consumptions. The RPM and rated power capacity are 920 and 187W, respectively.

2.2 Working Operation of a Cold Storage

For analysis of performance of cold storage for different stacking arrangement, vapor compression refrigeration plant using as working fluid R-22 is employed. The schematic diagram of the arrangement is shown in *figure 3*. The low temperature and low pressure vapor at state B is compressed by a compressor to high temperature and pressure vapor at state C. This vapor is then condensed into high pressure vapor at state D in the condenser and then goes to receiver where excess refrigerants not in circulation get stored.

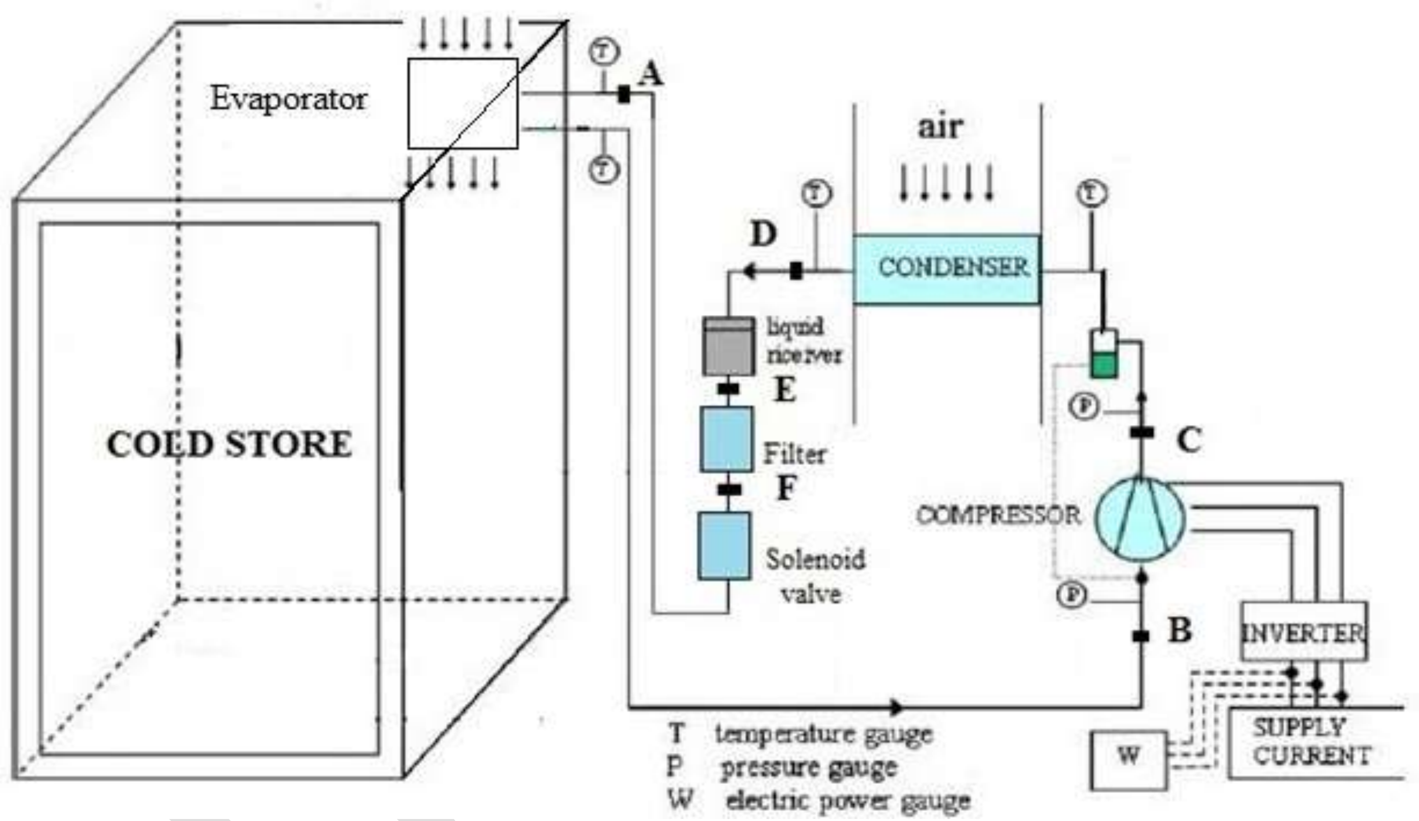

Figure 3 Line Diagram of Cold Storage

The refrigerant in circulation after receiver passes through filter where contaminants from refrigerant are absorbed by desiccants. Thereafter, the vapor goes to solenoid where vapor is throttled down to a low pressure liquid and passed on to an evaporator mounted on cold store wall, where it absorbs heat from the cold store by the circulating fluid (being refrigerated) and vaporizes into low pressure vapor at state B.

2.3 Cold Storage Description

The dimension of cold storage to be analyzed is 2.82m in length, 2.58m in width and 2.66m in height. In this cold storage, the product is kept in 45 crates and these crates with product are arranged in layer to make a rectangular stack within the chamber. The dimension of crate used to storing the product is 54cm in length, 36cm in width and 29cm in height. The crates are kept on the wooden platform, called pallet with dimension 1.2m in length, 1m in width and 0.0154m in height, having regular gaps of 3inch for a better air circulation in cold chamber. The crates are stacked one above the other. In this manner, total 5 crates exist in the vertical direction within cold chamber. The height of stacks is 1.45 m and there will be 9 stack columns.

3. STACKING ARRANGEMENTS

For uniform and rapid cooling within cold store, the crates of product should be so stacked that cold air from evaporator can be enabled to move throughout each individual crates. It is essential that crates are so arranged that air channel can be made in cold store for direct air movement and also there should be some gap between the crates and walls to enable refrigerated air to absorb the heat of conduct through the walls.

In this paper, we are carried out the performance analysis of cold storage for three different arrangements of stacks. The arrangements of stack are accomplished by providing the certain gap among the columns of stack. The different stacking arrangements are:

A. First Arrangement: In this arrangement, the columns of stack are separated with gap of 10 cm.

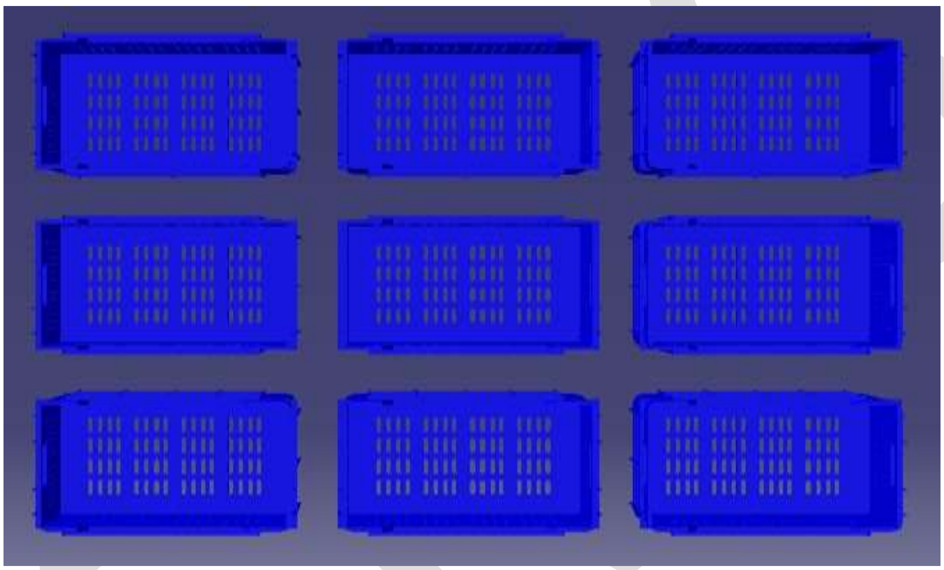

Figure 4 First Arrangement, Top View

B. Second Arrangement: In this arrangement, the columns of stack are separated with gap of 20 cm.

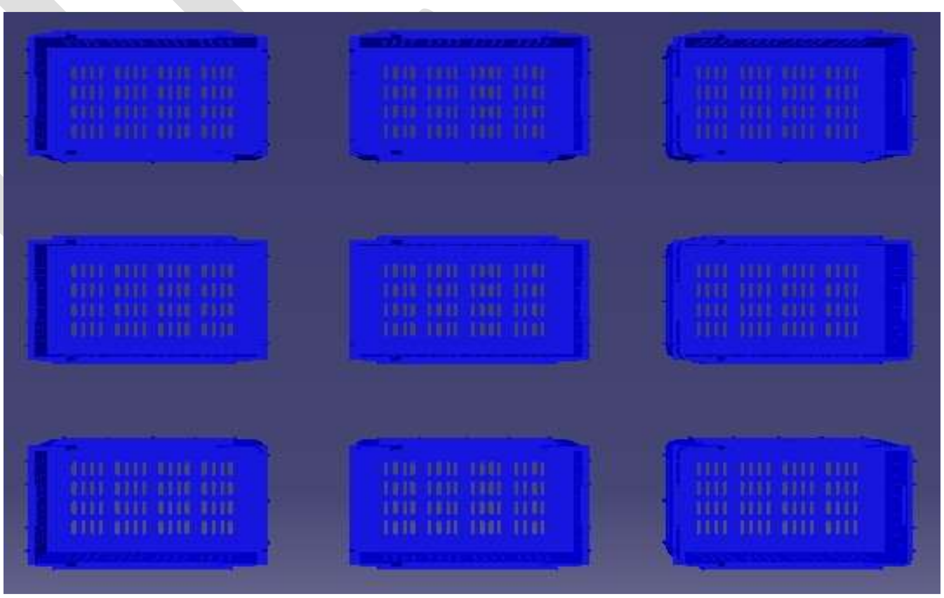

Figure 5 Second Arrangement, Top View

C. Third Arrangement: In this arrangement, the columns of stack are separated with gap of 30 cm.

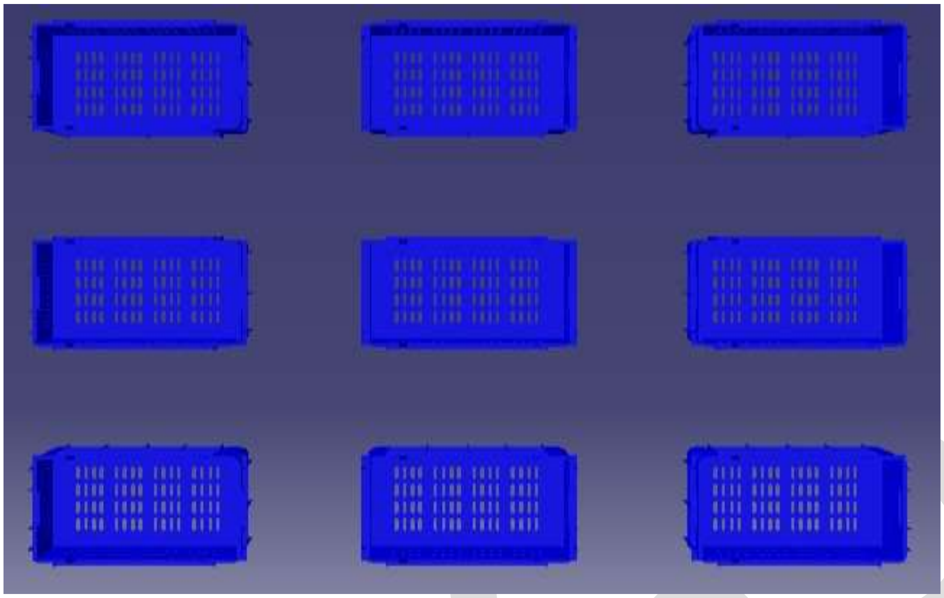

Figure 6 Third Arrangement, Top View

For uniform and rapid cooling within the cold store, the proper circulation of cold air is desirable. In order to have better circulation of cold air, stacking arrangement should be proper that it enables the cold air to circulate through each individual crates within the cold chamber.

4. OBSERVATIONS

The basic object of present work is to see the effect of stacking arrangements on the performance of cold storage. In this section, the average product temperature distribution for various stacking arrangements has been presented. The graphs of average product temperature distribution of 14 hours running of a cold storage for three different stacking arrangements with the gap of 10cm, 20cm and 30cm are plotted. For every arrangement, we are considering three planes at the different distance along length, width and height of the cold storage and each plane has 9 points of T-type thermocouple. The temperature distributions with time at different plane of different arrangements are recorded by digital temperature indicator and average valve of recorded product temperatures of each plane is depicted between coordinate axes. In all graph of temperature distribution, running time, in hours, of cold storage and average product temperature in ℃ of crates of same plane are presented along X- axis and Y-axis, respectively.

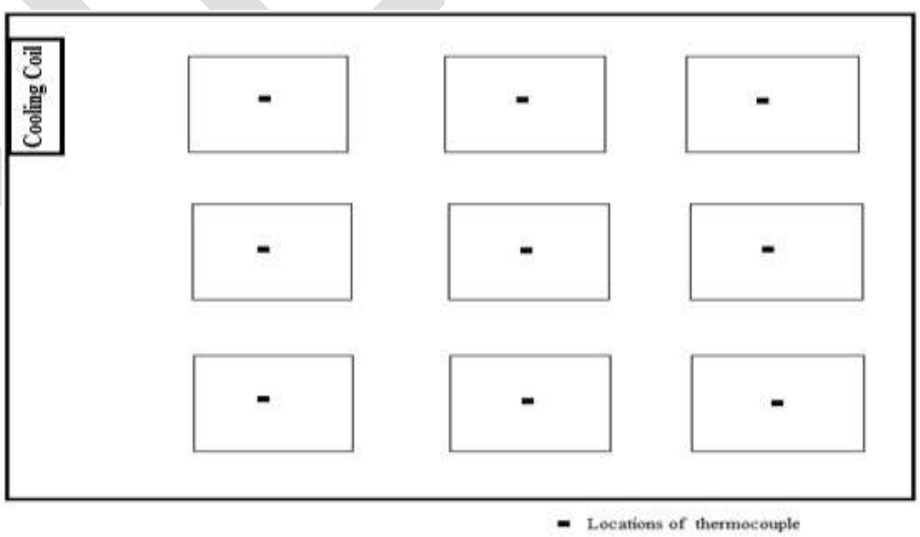

Figure 7 Different Locations of T-type Thermocouple on a Plane from Top View

A. First Arrangement

The average temperature distributions of different planes along length, width and height of cold storage are plotted as following:

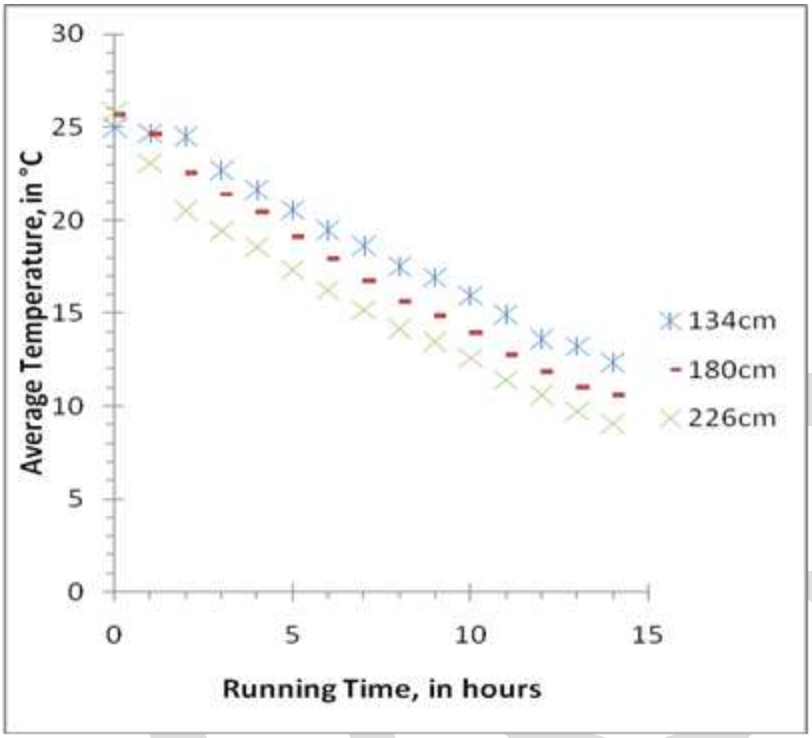

Figure 8 Average Temperature Distributions with Time, of Planes at Different Distance along Length from Front to Back in First Arrangement with Gap of 10cm

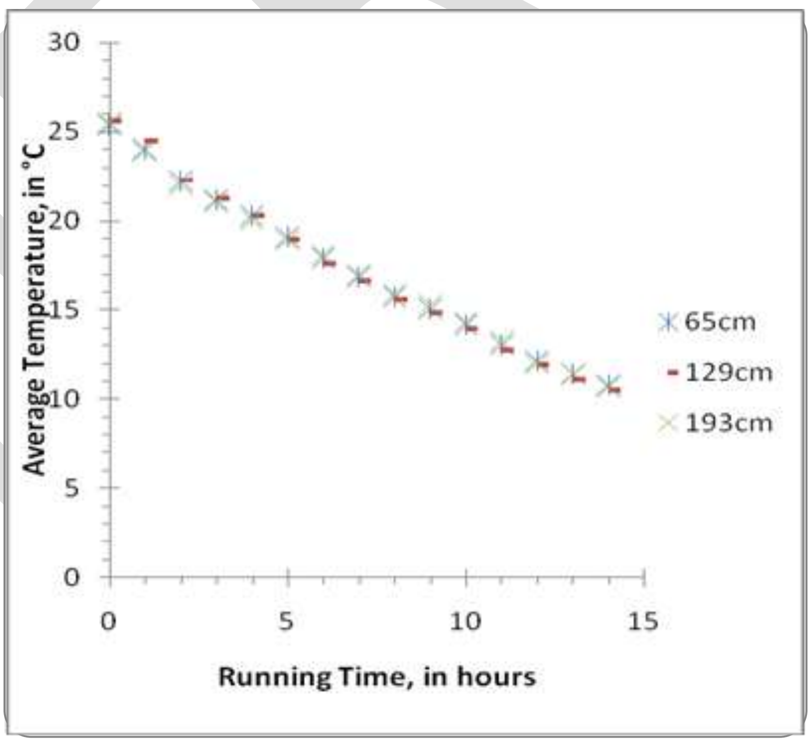

Figure 9 Average Temperature Distributions with Time, of Planes at Different Distance along Width from Left to Right in First Arrangement with Gap of 10cm

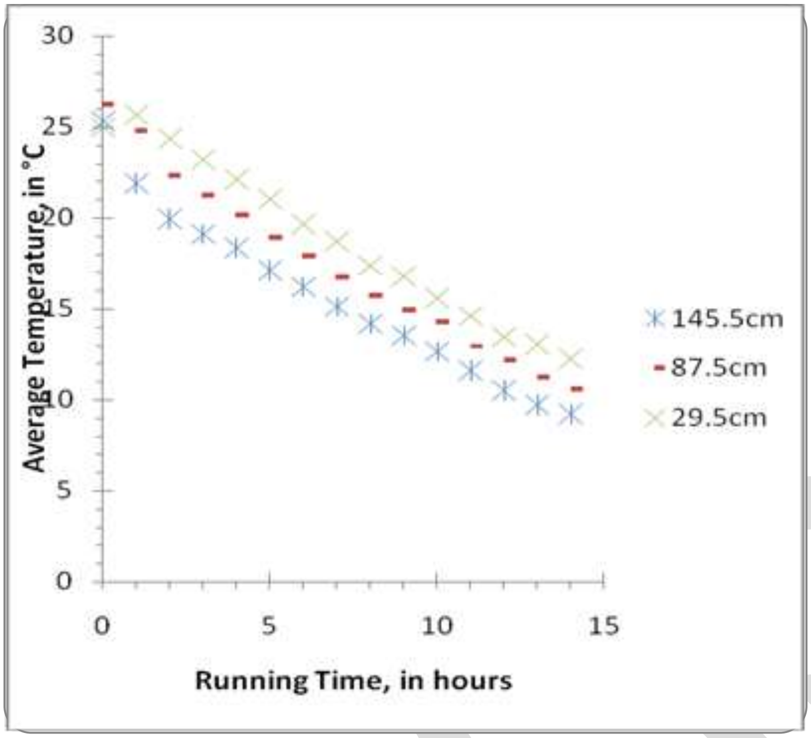

Figure 10 Average Temperature Distributions with Time, of Planes at Different Distance along Height from Top to Bottom in First Arrangement with Gap of 10cm

B. Second Arrangement

The average temperature distributions of different planes along length, width and height of cold storage are plotted as following:

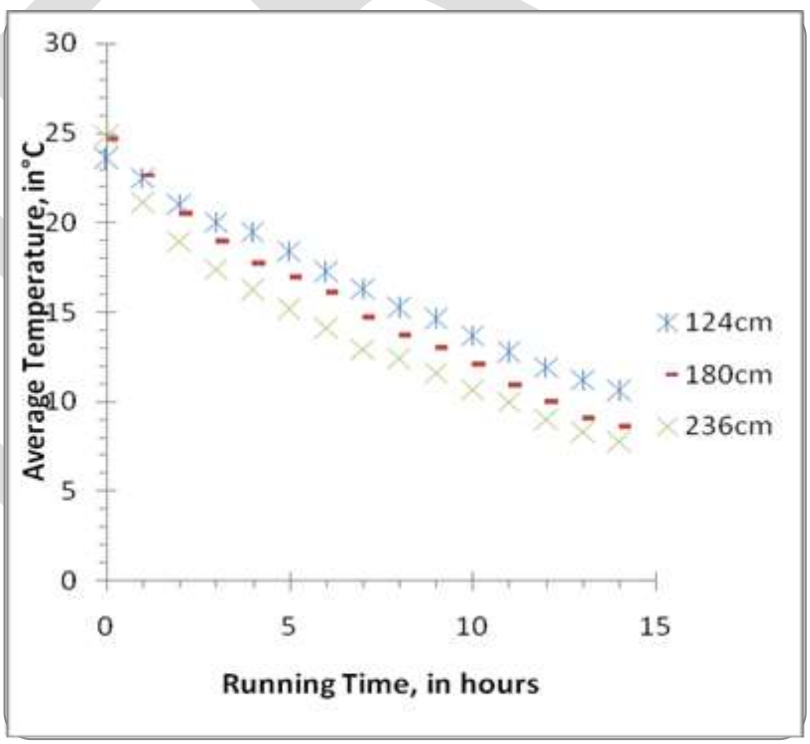

Figure 11 Average Temperature Distributions with Time, of Planes at Different Distance along Length from Front to Back in Second Arrangement with Gap of 20cm

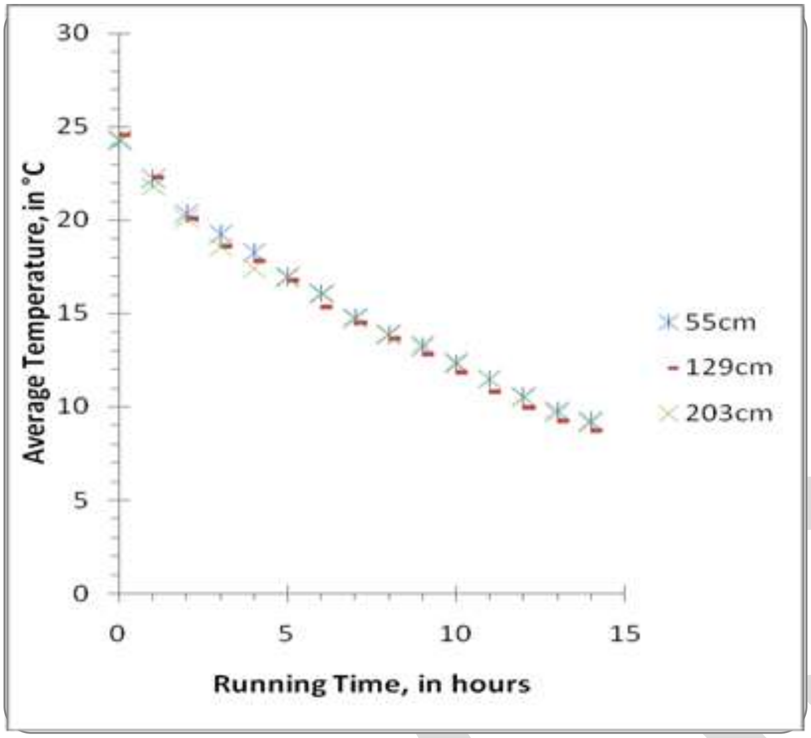

Figure 12 Average Temperature Distributions with Time, of Planes at Different Distance along Width from Left to Right in Second Arrangement with Gap of 20cm

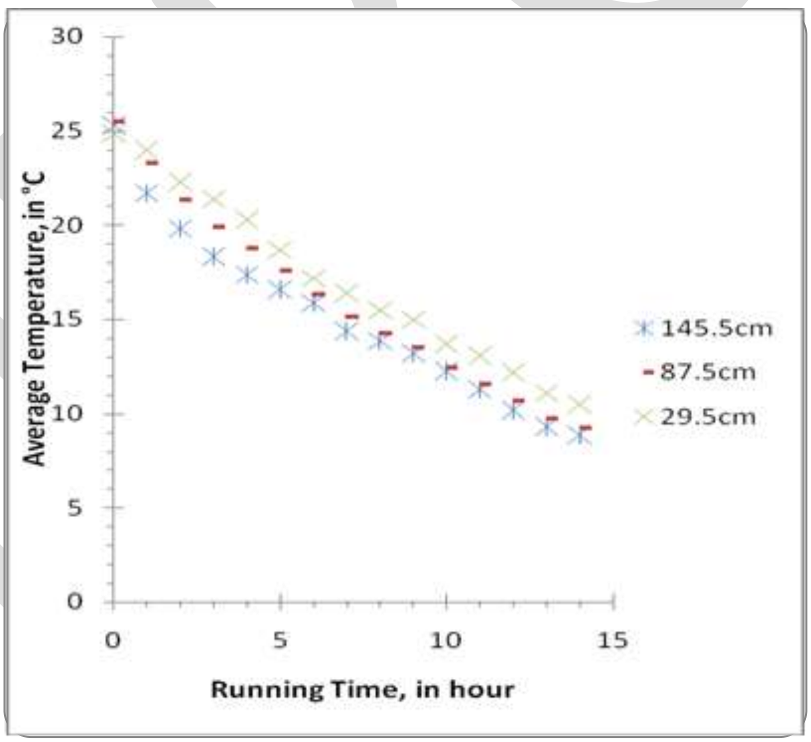

Figure 13 Average Temperature Distributions with Time, of Planes at Different Distance along Height from Top to Bottom in Second Arrangement with Gap of 20cm

C. Third Arrangement

The average temperature distributions of different planes along length, width and height of cold storage are plotted as following:

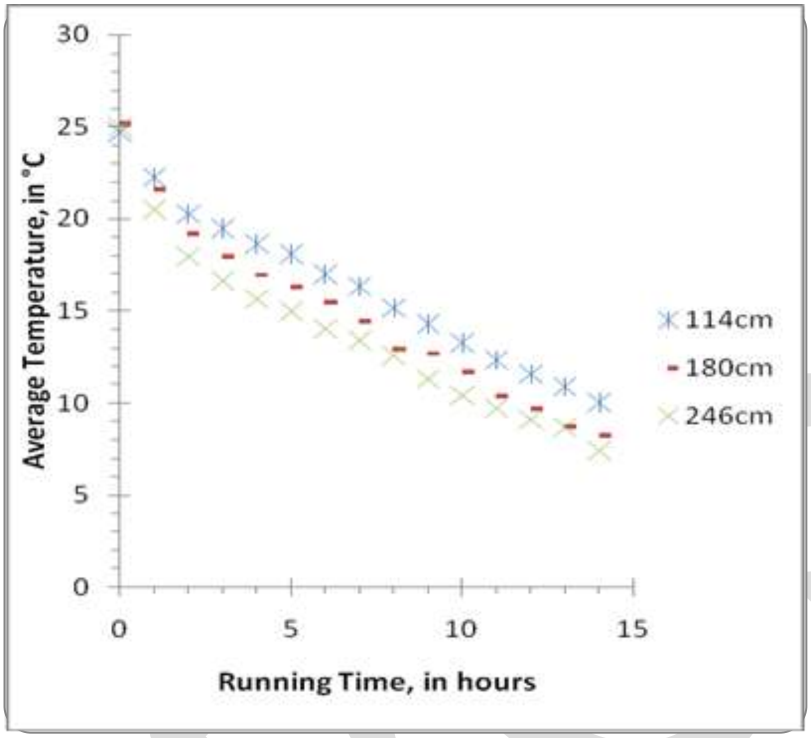

Figure 14 Average Temperature Distributions with Time, of Planes at Different Distance along Length from Front to Back in Third Arrangement with Gap of 30cm

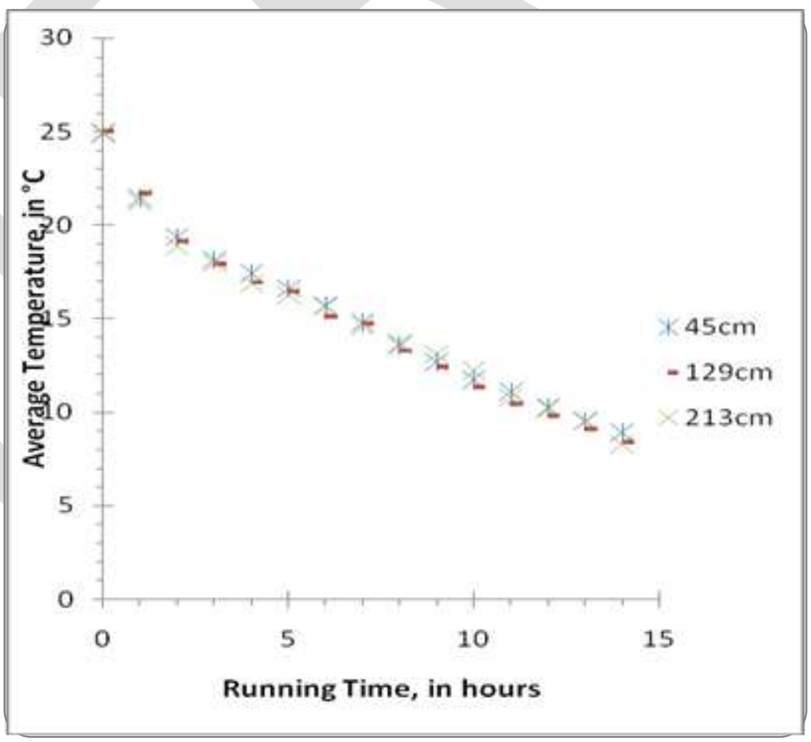

Figure 15 Average Temperature Distributions with Time, of Planes at Different Distance along Width from Left to Right in Third Arrangement with Gap of 30cm

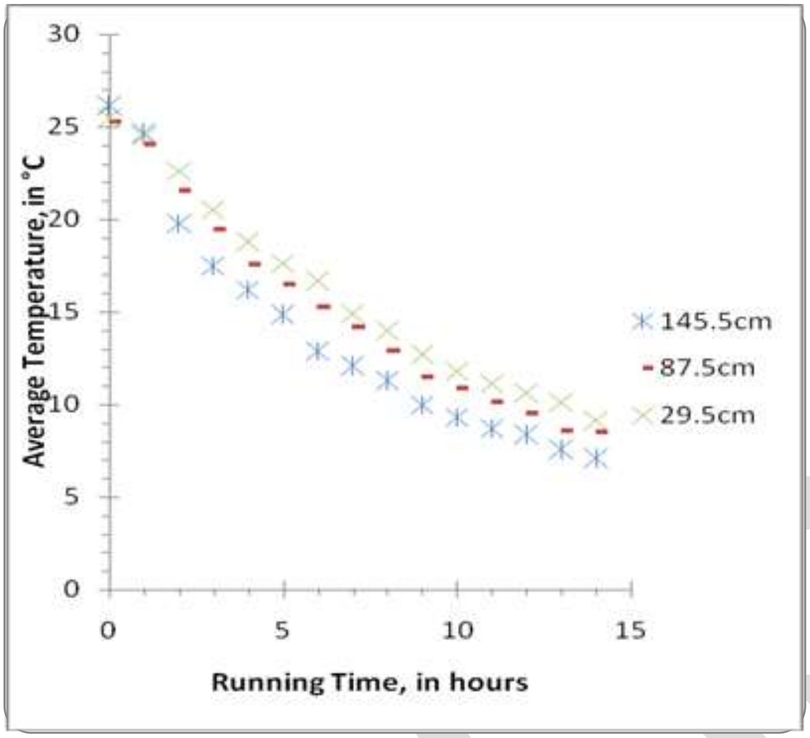

Figure 16 Average Temperature Distributions with Time, of Planes at Different Distance along Height from Top to Bottom in Third Arrangement with Gap of 30cm

5. RESULTS

The overall average temperature distributions of three different arrangements- first, second and third are shown in *figure 17*. From *figure 17*, it is observed that after 14 hours of running of cold storage, the third arrangement has achieved a lower temperature than others.

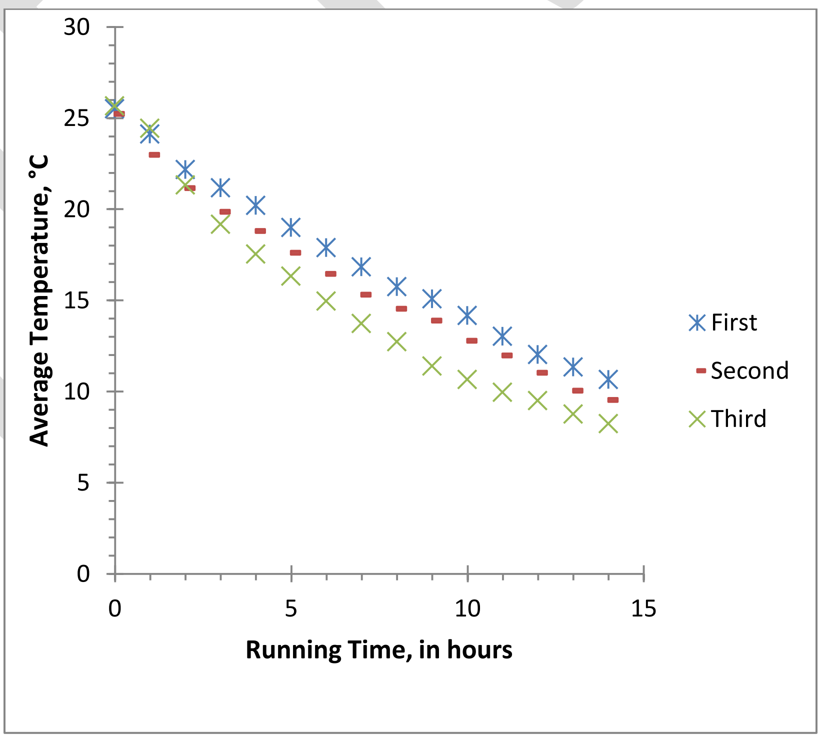

Figure 17 Overall Average Temperature Distributions in Cold Storage for Different Arrangements

Table 1: Results of Differernt Stacking Arrangements

Arrangement	Gap between columns of stack	Overall Initial average temperature (°C)	Overall Final average temperature (°C)	Surface Area (m^2)
First	10cm	25.5	10.66	2.33
Second	20cm	24.41	9.02	2.99
Third	30cm	24.97	8.23	3.73

Power Consumptions

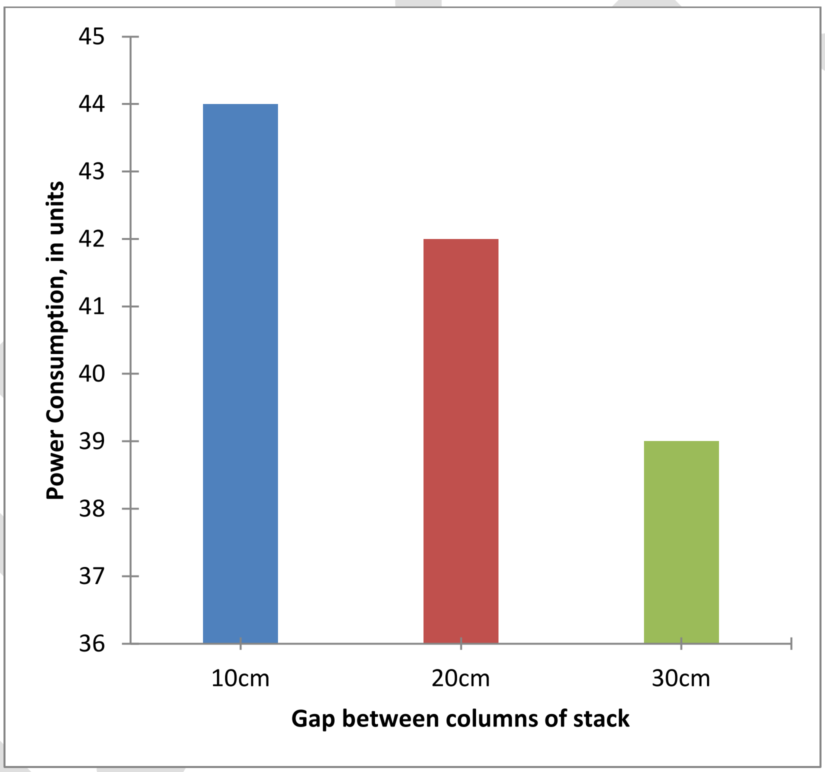

Figure 18 Power consumption of cold storage in three different stacking arrangements

From above *figure 18*, it is seen that the arrangement with gap of 30cm has consumed less unit of electricity.

6. CONCLUSION

The experiment is done for performance analysis of cold storage for different arrangements and their results are shown in *table 1*. Here, it can be concluded that-

- From average temperature distribution of different arrangement, it has been observed that on increasing the gap between the columns of stack, the tendency of achieving low temperature within the cold store is more. This is happened due to on increasing the gap between the columns of stack, the width of air channels in different arrangements increases accordingly. The increase in width of air channels give the way to air to be circulated to each individual crates within the cold storage.

- In this experiment, we have been emphasized over the three different arrangements with gap of 10cm, 20, and 30cm. Out of three arrangements, the third arrangement with gap of 30cm is most preferable. Because the average temperature of cold storage in this arrangement is low, i.e. 8.23 °C, as relative to rest of other two arrangements.

- The average temperature difference between second and third arrangement is not much more. It means that the temperature distribution becomes better on increasing the gaps between the columns of stack up to a certain limit after which it is not that much good.

- On increasing gap between the columns of stack, stacking arrangements require more space of cold storage.

- On increasing the gap between the columns of stack, power consumptions decrease.

- The increase in gap is also influenced the running time of cold storage. Lager gap provides more air circulation, resulting to achieve the optimal temperature of product rapidly.

From above conclusions, the third arrangement of stacks gives a better performance to cold storage and requires more space.

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