Transport Phenomenon Improvement Using Induce Draught in Cold Storage

Pankaj Mishra and K. R. Aharwal

Abstract Air is heat transport medium in cold storage operation and its distribution plays a vital role in preservation of agricultural products like fruits and vegetables with desired quality. Thermal behaviours of cold storage system are based on air transport arrangements. Convective heat transfer from stored perishable stuff to cooling system within the chamber is subjected to airflow and its distribution. Transport characteristics can handle with axillary arrangements such as induce draught system. Experimental investigation for impact of induce draught on air transportation is carried out in a 1/4th reduced scaled model of the cold storage [size 6 m (l) $\times$ 4 m (w) $\times$ 4 m (h)] at HT Laboratory, MANIT, Bhopal. Air transport velocity was measured at 96 stations in the chamber with hot wire anemometer. Measurements indicate supply air approaches rear section of the chamber comparatively at higher velocity with induce draught. Markable improvement noticed with slotted duct wall which boosts airflow velocity by three times at mid-sections compare without induces draught. Overall 1.5 times to three times better supply airflow velocity observed in the chamber, as compare to general configuration, while return air velocity measured almost double during the experiment. Experimental results suggests shift of turbulence mixing of air from evaporator side to central zone of the chamber. Better mixing of air can help in a fast setting of thermodynamic equilibrium in the chamber. It will lead to homogenous thermal environment which can extend the life of perishable goods with maintaining their quality.

Keywords Cold storage · Air transportation · Induce draught · Duct · Preservation

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1 Introduction

Cold storages accommodate biodegradable items to preserve them at very low (frozen or chilled) temperature, with desired quality [1]. Efficient cold storage operation depends on various factors like chamber geometry, size and capacity of evaporator along with its mounting position, wall insulation, stockpiling arrangements, items stored and airflow distribution. [1, 2]. Airflow pattern or flow distribution is very crucial factor for life and quality of preserved food items in cold chamber. Heterogeneity in airflow causes various temperature zones in camber and it results in uneven cooling rate of stored products [1]. Samuel et al. exhibit in their research that effects of stacking arrangements on airflow and show various temperature zones in the chamber set-up due to airflow variation in chamber [2]. Irregularity in airflow causes loss of foodstuff because of high respiration rate at high temperature or injury due to frosting at low temperature [3]. Heterogeneous supply air distribution leads to higher relative humidity zone which is responsible for deterioration of potatoes because of moisture condensation at various parts of stacking [4]. Thermal behaviours of cold rooms can be altered with various ways like evaporator coil repositioning, fan speed variation and stacking arrangements changes.

Researchers were observed higher temperatures zones, because of the stagnant zones with poor ventilation in the rear part of the cold storage chamber [5–7]. To address stagnant zone problem in cold chamber, a reduced scale model is adopted in this research work. Experimental investigation of cold storage transport phenomenon is a costly affair thus most of the researchers adopt computational techniques like CFD for their research. Airflow in cold chamber analysed for various stacking arrangements, evaporator passions or for blower speed but use of auxiliary methods like induce duct, of baffled surface or other means were not considered for cold storage air distribution analysis.

In the operation of thermal power plants, kitchen and building exhaust system reverse or induce draught with duct well-established concept for enhance the flow velocity in stagnant zone. Reverse duct is a structure which produces induce draught, which causes airflow in the direction of duct, as chimney draught does in power plant. As large space of cold storage and close air circulation are major constrains for natural draught setup in cold room for the same artificial induce draught can serve the purpose.

Evaporator coil throws supply air axially along the length of the room but supply air is not able to cover whole length of the room because of flow resistance and obstacles in airflow path. As a result, stagnant zone or low airflow zone is created at rear part of the cold room. In stagnant zone, heat transfer rate through convection is low, and it may cause damage of stored foodstuff.

Presented work demonstrates effect of induce draught on airflow circulation in cold chamber with the help of flow velocity measurements at different sections of room for various conditions. Alvarez and Flick [8] find hot wire anemometer suitable to measure flow velocity, with the help of that they had investigate turbulence intensity in a cold storage chamber they also demonstrated turbulence generation on sphere bed in airflow, when it penetrates media. Hot wire anemometer is used in present research work for flow velocity measurements.

2 Experimental Set-up

A cold storage prototype of 6 m (l) × 4 m (w) × 4 m (h) (at MANIT, Bhopal) was taken as reference to developed scale model for visualization purpose of airflow characteristic inside the cold storage. Model is prepared in ratio of 1:4, i.e. 1.5 m (l) × 1 m (w) × 1 m (h) with transparent acrylic sheets of 3 mm thickness. Tapsoba et al. successfully used reduced scale model for cold storage chamber mounted on truck for airflow investigation. The model was used to demonstrate and analyse of effects of various factors on airflow velocity pattern inside a cold store [9].

Geometrical and kinematic similarity is desirable between model and prototype. Model is geometrical similar with 1/4 reduction ratio as compare to prototype. For kinematic similarity, common range of Reynolds number for model and prototype is desirable. To calculate Reynolds number for prototype cross-sectional area for evaporator is 0.6 m × 2 m (1.2 m^2) where flow velocity at outlet of evaporator average is 1 m/s is considered. Reynolds number for prototype is calculated at the temperature of 25 °C is Re_p = 59,090.91. Likewise for model evaporator cross section is 0.5 m × 0.16 m and average flow velocity, according to flow capacity required as discussed further, is selected 3.5 m/s. Reynolds number for model at 25 °C is calculated Re_m = 54,449.43.

Reynolds number calculated for both has a difference of 7.85%, while taking allowance of 10% for model, Reynolds numbers are approximately in same range.

Flow capacity required for model can calculate as by Eq. 1.

$$\frac{C(\text{flow capacity})\,\text{m}^3/\text{h}}{V(\text{Volume of cold room})\,\text{m}^3} \tag{1}$$

$$\frac{C_\text{p}}{V_\text{p}} = \frac{C_\text{m}}{V_\text{m}} \tag{2}$$

where C_p is flow capacity of prototype evaporator and V_p is volume of prototype, C_m and V_m are flow capacity of evaporator and volume of model, respectively.

$$\text{Volume of prototype cold room} = 96\,\text{m}^3$$

$$\text{Volume of model} = 1.5\,\text{m}^3$$

$$\text{Capacity of evaporator coil for prototype} = 8640\,\text{m}^3/\text{h}.$$

Thus, flow capacity for evaporator's fan in model is calculated 2.25 m^3/min or 135 m^3/h. Four axial blower fans with 0.57 m^3/min rated capacity each were chosen for the model with overall capacity of 2.28 m^3/min.

Airflow velocity measurement within cold storage chamber is a difficult work as there is turbulence present in flow because of this flow direction is not fixed, along with this reason, there is no robust and accurate device is available for flow measurement [10]. In this research work, HTC AVM 08 hot wire anemometer (shown Fig. 3b) used. It can measure air velocity in the range from 0.1 to 25 m/s with 0.01 m/s resolution. The line diagram of the experimental set-up and its photographic view is shown in Figs. 1 and 2, respectively. Line diagram represents basic arrangement of set-up and airflow direction in the chamber. Evaporator with axial blower fan is fitted such that its midpoint is 86 cm above the base of the chamber, 14 cm from back side wall and 50 cm from both side walls as shown in Fig. 1. Front face of evaporator is 22 cm from back wall.

Test is conducted on scaled model for the following three conditions:

- General configuration (without duct arrangement)
- With induce duct arrangement
- With induce duct wall having equally spaced slots cut on it.

General configuration deals with only closed chamber equipped with evaporator and measuring arrangements, no other auxiliary arrangements are placed inside the chamber. It is similar to empty cold storage plant. In this case, flow velocity in chamber was measured along the vertical central plane at different locations which were marked along the length and height of vertical planes as shown in Fig. 3a. Total ninety-six (96) stations were selected for velocity measurement.

Velocity of airflow also measured in reverse direction as well to map pattern of return air. In closed chamber, air circulation is established, i.e. supply cold air thrust

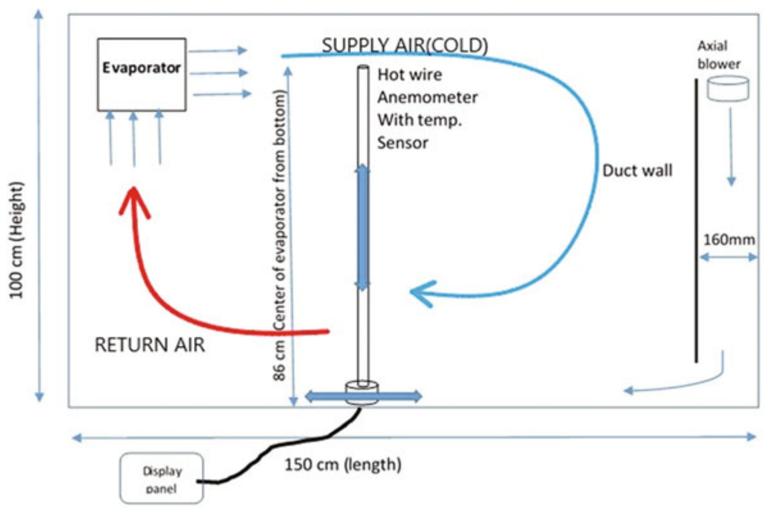

Fig. 1 Line diagram and actual photograph of experimental set-up

Fig. 2 Actual photograph of experimental set-up

from evaporator is return back to it as shown in Fig. 1. Air circulation insures convective heat transfer from products to refrigerant.

For second configuration testing, induce draught system is placed at rear section of chamber, where reverse duct with two axial blowers, of flow capacity 0.57 m^3/min per blower, were mounted. Duct wall is placed 16 cm away from rear wall of chamber (Fig. 1) with a gap of 11 cm from top plane and 10 cm at bottom plane. Two axial blower fans are placed in gap to force air in downward direction. These fans have mass flow rate is 1.14 CMM in combination. These fans create pressure drop as a result induce airflow through duct section.

Third experimental configuration consists of two equally spaced horizontal slots of 12 cm × 84 cm cuts on the duct wall along width of it. Fans in evaporator section run at their full combine rated capacity, i.e. 2.28 m^3/min.

3 Result and Discussion

Airflow velocity measurements were conducted inside the model cold storage chamber for all three above-stated configurations. Velocity profile plotted between airflow velocity and length of room. Figure 4 represents velocity profile for general configuration. Evaporator fans run at their full capacity without any additional flow affecting medium in the chamber. Supply airflow velocity 10 cm in front of evaporator is almost same as that of the fan's air thrust velocity, i.e. 3 m/s. Flow velocity continuously drops from evaporator end to rear part of the chamber, as supply air move away from the evaporator section. Initially, rate of velocity drop is quite high as just 50 cm away from evaporator flow velocity remain half of the initial velocity. At 90 cm away from evaporator coil and 86 cm above ground, velocity became almost 83% less that of the initial value. Supply air velocity at

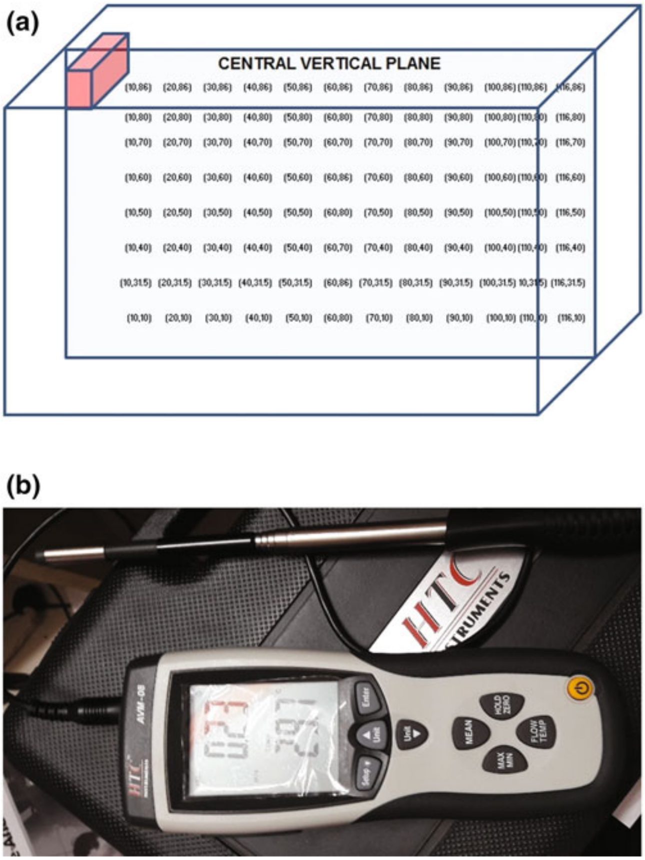

Fig. 3 Measurement location map and instrument used. **a** Location map for observation. **b** HTC AVM -08 hot wire anemometer

50 cm above the ground recorded 1.3 m/s near evaporator and 0.25 m/s at rear section of the chamber. The results indicate that supply airflow velocity is very low at the farthest part of the chamber, because of that poor mixing conditions are prevailing. Results indicate that airflow near the evaporator coils is highly turbulent and because of this good convective heat transfer rate is likely in this part of chamber. Lowest supply air velocity was observed near rear wall of the chamber at 10 cm above ground was 0.27 m/s. Return air move through evaporator's bottom section as shown in Fig. 1. Close air circulation is setup in side the chamber as, there is no leak of air neither outward nor inward to cold storage.

In Fig. 4, airflow velocity in reverse direction plots with legends having negative signs. Plots show that return airflow velocity pickup just below evaporator section, as evaporator draw maximum airflow from its bottom and throw it axially in positive X distraction. Return air velocity at 10 cm in front of evaporator,

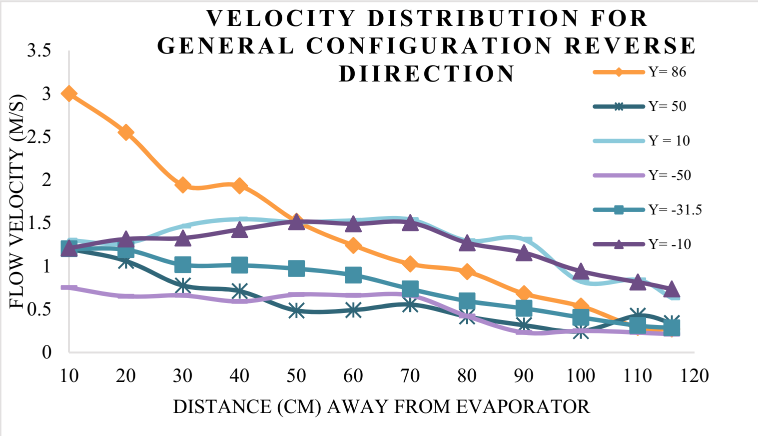

Fig. 4 Flow velocity versus distance form evaporator graph; flow away from evaporator and flow towards evaporator (value with (−) sign shows flow towards evaporator) for cold chamber in general configuration

31.5 cm above base is 1.2 m/s and it is 1.3 m/s at 40 cm above the base. Measurements for general configuration clearly illustrate that there are certain areas in the chamber where airflow is not properly reached because of that heat transfer suffer in those sections.

It is clear from the above discussion that there is a need to build such arrangements which would be able to improve flow distribution in such a manner so that supply air can reach farthest parts of the chamber. On the basis of above discussion, the concept of induce duct is introduced here as a solution. In Figs. 4 and 5, results were plotted which indicated the impact of induce draught on cold storage chamber in terms of velocity profile.

An induce duct arrangement is placed opposite to evaporator section or in rear section of chamber. Figure 5 represents effect of duct on airflow pattern in chamber, and it indicated that there is a significant rise in flow velocity inside the chamber because of induce draught arrangements.

On comparing Figs. 4 and 5, it is observed that airflow inside the chamber is improved when reverse duct system is in action. Graph plotted for velocity profile represents that at 86 cm above ground and 110 cm in front of evaporator, the flow velocity is improved from 0.5 to 1.4 m/s. It reflects that because of induce duct the reach of supply airflow improved in farthest parts of the chamber. The flow velocity was almost fifty present at mid-way if induce draught was not used.

On the observation of velocity profile (Fig. 5) for return airflow when induce drought is in operation, it is found that return airflow velocity is 35–44% more as compared to general configuration. Induce draught clearly improves flow at top and bottom section as flow velocities were higher as compare to general configuration, but central region is merely affected. Flow velocity in central zone, i.e. at 40 cm in

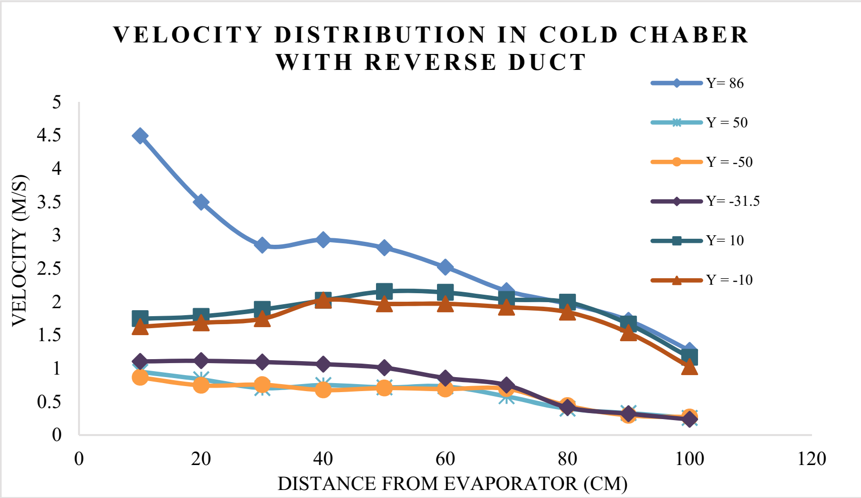

Fig. 5 Flow velocity versus distance form evaporator graph; flow away from evaporator and flow towards evaporator (value with (−) sign shows flow towards evaporator) for cold chamber with reverse duct

front of duct and 40 mm above base is marginally affected by reverse duct and values of velocity similar as in the first condition. To overcome this situation, slots were cuts on duct wall as discussed in experimental set-up section and measurements were taken for the same, results are as indicates in Fig. 6.

Observations made for the third configuration indicted that flow velocity is slightly drop at top level of the room, but overall flow velocity was improved in remaining parts of the chamber. Even though return airflow is also improved as compared to first two cases. Velocities were recorded for third configuration, 9–16% higher as compared to the second configuration at mid-parts of the chamber. More ducting arrangements may be tested for better solution.

Experimental results as discussed above indicate that induce duct system can improve the airflow distribution in cold chamber. Slots cut on induce duct in the last case further improve velocity, especially in mid-section of cold chamber. Experimental results conclude that use of induce duct is advantageous in cold storage operation as because of this uniform flow distribution reduce the load on cooling system. More convective heat transfer could be possible because of proper mixing of air. Results suggest that with reverse draught air movements in the chamber is cover all parts that insure even temperature distribution. Uniform temperature distribution ensures reduction in frosting chance inside the chamber.

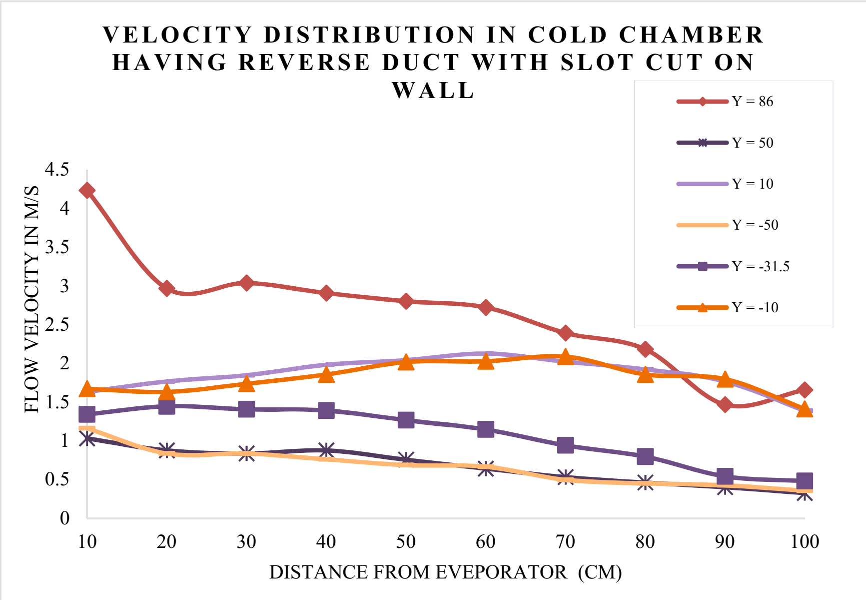

Fig. 6 Flow velocity versus distance form evaporator graph; flow away from evaporator and flow towards evaporator (value with (−) sign shows flow towards evaporator) for cold chamber with reverse duct and slot cuts on duct wall

4 Conclusion

In the present study, the velocity distribution and instantaneous temperature of flow air inside the cold chamber for three different conditions have been investigated. Results show that there is significant improvement in airflow velocity with induce duct arrangement. The use of induce duct is advantageous in cold storage operation as it will be able to maintain uniform flow distribution inside the chamber which reduces cooling load on refrigerating system. The proper air circulation will also ensure reduction in frosting chance inside the chamber and increase the life of food articles. More reverse ducting arrangements with various position and size of slots and blower fans can be investigated for future research work. In this investigation, empty cold storage was used, for better picture same investigation can repeat with live load of agricultural products.

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