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RESEARCH PAPER

Development of evaporative cooling mobile vending cart for vegetables

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Abstract : Post-harvest losses of fruits and vegetables are impacted by lack of adequate low-temperature storage and transportation facilities. The present traditional vending system of handling fruits and vegetables by street vendors causes loss of weight due to lack of cooling system. Solar powered evaporative cooling vending cart operating at reduced temperature was developed and evaluated for its performance loading vegetables namely spinach, fenugreek, brinjal, tomato, cucumber and chilly in the month of February, April and September. The mean drop in temperature was observed 10.21±0.41°C, 8.97±0.46°C and 3.37±1.21°C, whereas mean per cent-increase in relative humidity was 216.54±46.77%, 184.59±12.63% and 130.20±5% observed inside the storage chamber during the month of February, April and September, respectively. Per cent saving in physiological loss in weight (PLW) was highest (62.5%) in spinach, followed by tomato (57.27%), brinjal (53.62%), cucumber (51.97%), chilly (31.69%) and fenugreek (30.30%) as compared to ambient (control). Saving in weight was more than 0.14kg.kg^{-1} of vegetables over control.

Key Words : Two-stage evaporative cooling, Solar-powered mobile vending cart, Fruits, Vegetables, Temperature, Relative humidity, Physical loss in weigh

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INTRODUCTION

Most of the post-harvest losses incurred on fruits and vegetables is due to ambient hot wea ther and lack of adequate low temperature storage (Jha, 2008 and Das *et al.,* 2018). Indian roadside vegetable vendors find it difficult to keep the vegetables fresh to sell during the day-hours. Lack of cooling facilities in mobile vending cart leads to loss of weight in fruits and vegetables through heat; they wilt, look bad and become unattractive to the customer. Hence, as vegetables approach spoilage, vendors are forced to sell at lower prices and even to discard spoilt produce, thereby loosing income.

It is estimated that about 35-40% of India's annul fruits and vegetables harvest is lost through spoilage, primarily because of poor storage, and that much of these losses occur at roadside vending carts (Samuel *et al.*, 2016 and Sharma and Mansuri, 2017). The wastage of fruits and vegetables, particularly leafy vegetables, at local markets / road side carts are in general high (Vala and Joshi, 2016). At present low-cost efficient cooling system for the preservation of fruits and vegetables for street vendors are not widely available. Mechanical refrigeration is well established efficient technology for storage of fruits and vegetables, but, it is not affordable to such vendors because of their high capital and operation cost. Evaporative cooling is a low-cost, minimal energy, efficient, inexpensive, environmentally benign, and proven system for storage of fruits and vegetables. Cooling by evaporation of water is an ancient but effective method of lowering temperature that operates using induced processes of heat and mass transfer and is suitable system for storage of fruits and vegetables in hot and dry country like India (Jha 2008; Vala and Joshi, 2010 and Potdukhe *et al.*, 2018).

Samuel *et al.* (2016) developed a solar-powered evaporative cooled vegetable vending cart, having storage chamber below the open top surface and vegetable kept on it open for selling as in traditional ca rt and reported that the maximum drop in temperature of 11.2°C and increase in relative humidity of 25% observed inside the vending cart chamber with considerable saving in physical loss in weight and increased shelf-life. A solar-powered evaporative-cooled air-conditioning type vending cart using heat-exchanger developed by Ingale *et al.* (2018), having open storage chamber and cooling unit kept on top cover, reported that the maximum drop in temperature up to 11°C and 25 per cent increase in relative humidity. Potdukhe *et al*. (2018) developed a solar assisted three wheeler cycle rickshaw type vegetable cart for short-term storage of fruits and vegetables by incorporating evaporative cooling system and reported that inside temperature of cooling chamber maintains 18-20°C. All these vending cart have open storage chamber (vegetables to be sale kept open on top cover) and having single type cooling system.

Most of the freshly harvested fruits and vegetables contain 65-95% water, and cooling is thus important to maintain freshness and minimize quality loss when sold by the vendors. The cost is high in developing mechanical refrigeration system on a movable vegetable cart. Also the solar-powered vending cart so far developed are open type, having single cooling system, for storage only, also vegetables to be sell kept open without cover in top surface same as in traditional cart. In view of the above, vending-cum-storage type solar powered eco-friendly vegetable cart developed having two-stage evaporative cooling system to provide a low-cost viable system.

MATERIAL AND METHODS

Development of vending cart :

A solar-powered vegetable vending cart was developed by considering the traditional four- wheeled vending cart dimensions (length, width, height) and necessary modified to accommodate an active cooling system and a storage chamber. The original dimensions of traditional vending cart (1700×1100×800mm) were considered for conceptual design (Fig. A). Accordingly, a conceptual line diagram was prepared and fabricated as shown in Fig. B. Various components of the vending cart, namely; (i) cooling unit in which two-stage evaporative cooling system is fitted, (ii) storage-cum-display unit for storage of fruits / vegetables (iii) solar power system consisting of SPV with battery for supply of power to a fan and a water pump, and (iv) water distribution arrangement. Component wise details is given s under :

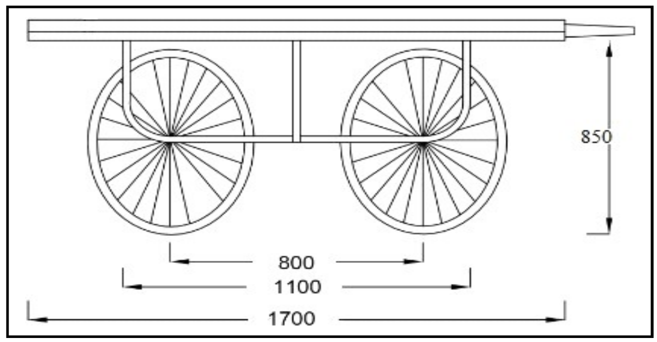


Fig. A : Traditional vending cart

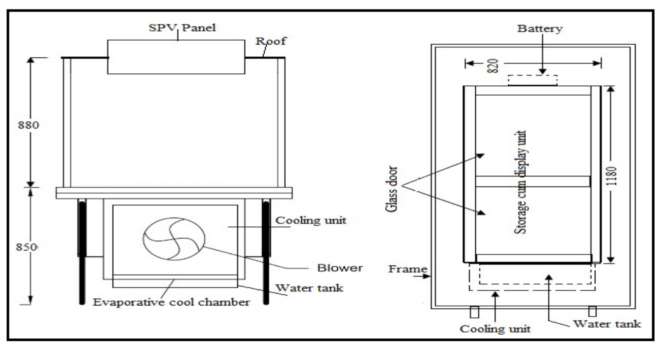


Fig. B: Conceptual line diagram with arrangement of components

Two-stage evaporative cooling unit:

In order to achieve cooling near the wet-bulb temperature of supply air, a two-stage evaporative cooling system (Fig. C), consisting of indirect-type first stage followed by direct-type cooling system was used. In indirect-type cooling a finned-tube type heat exchanger (aluminium radiator having 33 tubes, single row, 360mm length of tube with top and bottom cover having inlet and outlet pipe for water) was used, whereas wet-pad type evaporative cooling system (100mm CELdek pad, and 2.5lpm) used in direct-type cooling system. This cooling unit fitted on one side of the storage chamber (Fig.B). To get maximum cooling inside the chamber available area (820×400mm) of the chamber covered with the cooling unit. A pad holder was used to hold the wet-pad firmly. A fan (DC, 12W) was placed before the cooling unit to blow air (@2.4ms^{-1} and a small water pump (30W, 900lph) used to circulate water. The overall dimension of the combined indirect-direct cooling unit was 820×350×400mm.

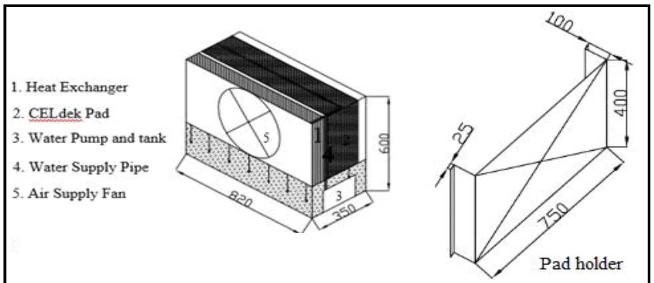
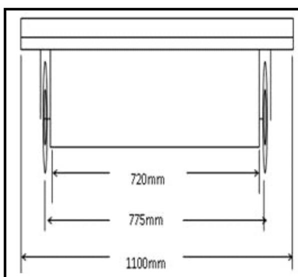


Fig. C: Two stage evaporative cooling unit

Storage chamber-cum-display unit :

A storage chamber (1180×820×400mm) was fabricated considering the space available between main frame (Fig. D and E). Cooling unit fitting side wall of the storage chamber wall was made perforated (820×400mm) for circulation of cooled air inside the storage chamber, also opposite wall also made perforated (5mm dia. equi distance) for exit of air (Fig. E). The top of the storage chamber was covered with sliding glass type window for display as well as loading and unloading of fruits and vegetables. A roof (made of ss bar and aluminium composite panel, 880mm height) was also provided on top of the chamber in order to prevent falling of sun rays over the display unit. The storage-cum-display chamber made closed, hence dust proof. Also user can lock it doors, if required.



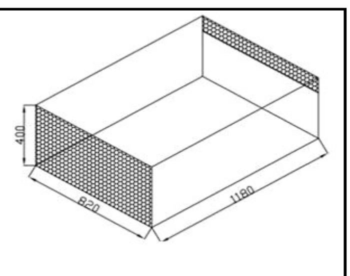


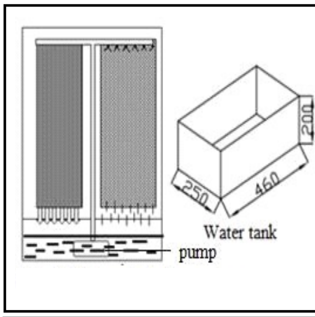
Fig. D: Dimensional view of traditional cart **Fig. E: Storage chamber**

Water distribution system :

For circulation of water in the heat exchanger and simultaneously spray water over the cellulose pad, a small submersible water pump (Voltage: 160-240/50Hz, power: 30W, head maximum: 1.65m, discharge: 900lph) with piping arrangement was assembled (Fig. F). A small water tank (460×250×200mm, 15 l capacity) was provided below the cooling unit. Water coming out from heat exchanger and wet-pad system collected in the same tank and re- circulated again.

Solar power system :

For supply of power to the water pump and electric fan, a solar power system consisting of a solar photovoltaic panel (SPV, 150Wp) with battery (12 V, 70AH) backup was provided. Sizing of he solar photovoltaic panel and battery was decided by considering peak power wattage required to run the fan (12w) and water pump (40w pump) as per standard calculations. Solar battery (12 V, 70AH) was used to store extra power during the sunshine hours, which could be utilized to run the system during off-sunshine hours. The solar photovoltaic panel was fitted on the top of the cart roof (Fig. G).



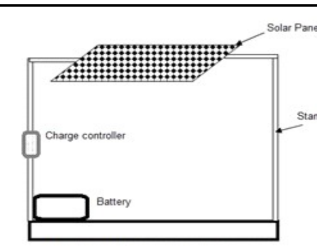


Fig. F: Water circulation system **Fig. G: Solar power system**

The developed vending cart was evaluated for its actual performance in terms of drop in air temperature, increase in relative humidity and saving in physiological loss in weight by loading few locally popular and widely available vegetables namely fenugreek *(Trigonella foenum- graecum)*, Spinach, brinjal *(Solanum melongena)*, bottle gourd (*Lagenaria siceraria*), chilly (*Capsicum frutescens*), tomato *(Solanum lycopersicum*), and cucumber *(Cucumis sativus*) at a time for a day. The vegetables procured from a (Amul road market, Anand) were cleaned and sorted before experiment. Samples 10 kg of each of the selected vegetable were prepared. The data regarding temperature and relative humidity both inside of the storage chamber and outside (Manson's mercury thermometer, range: 0-50°C, model FM 23006) were recorded using a thermo-hygrometer at 30min time interval. For estimation of loss in weight, initial weight (Model: TD-120, max- 120kg, min-5kg) of vegetables were recorded. The changes in weight of the control as well as of the cart were recorded at the end of the day.

Automatic sensor type thermo-hygrometer (Frontier, Model: 288CTC, range: 20-99%) used for recording of observation inside the storage chamber. The drop in temperature and increase in RH inside the storage chamber was calculated as:

Drop in temperature = (entering air temperature) – (air temperature inside the storage chamber at centre) ...(1)

Increase in RH,(%)={inside storage chamber RH (%)-ambient air RH (%)} ... (2)

The per cent loss in physical weight of the vegetables and saving in physical loss over control in percent was calculated using the Eqs. (3) and (4).

$$\text{Per cent loss in weight} = \frac{(\text{Initial weight,kg} - \text{Final weight,kg})}{\text{Initial weight,kg}} \text{x100} \quad .(3)$$

$$\text{Saving in PLW over control,(\%)} = \left\{ \frac{\text{Per cent saving with vending cart} - \text{Per cent saving in control}}{\text{Per cent saving in control}} \right\} \text{x100} \quad .. (4)$$

Results and Discussion

The experimental findings obtained from the present study have been discussed in following heads :

Variation in temperature and relative humidity :

The variations in mean temperature and relative humidity inside the storage chamber and outside during load tests for the month of February, April and September are shown in Fig. 1, 2 and 3. It was observed that the mean temperature inside the storage chamber was maintained at 22.82±1.19°C, 27.43± 0.97°C, and 29.42±1.13°C as against outside conditions 33.04±1.41, 36.12 ± 0.52°C and 32.37±1.80 during the month of February, April and September, respectively. The mean relative humidity inside the chamber was observed 76.61±10.38%, 74.34±2.26%, and 91.42±5.57% (70.42±5.65) as against outside relative humidity of 35.38 ± 9.48%, 40.92±5.36% and 70.42±5.65% for the February, April and September, respectively. The maximum temperature drop of 10.21±0.41°C, 8.97±0.46°C and 3.37±1.21°C observed during the month of April and May, respectively. The cooling system maintained low temperature and high relative humidity inside storage chamber as compared to ambient condition, this retards loss of water from vegetables and preserve the freshness of vegetables for longer period of time.

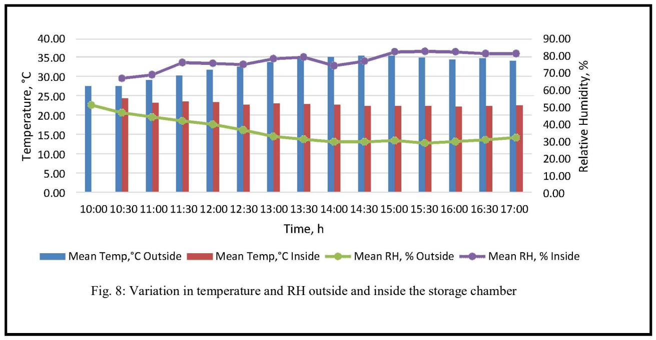


Fig. 1: **Variation in temperature and RH outside and inside the storage chamber**

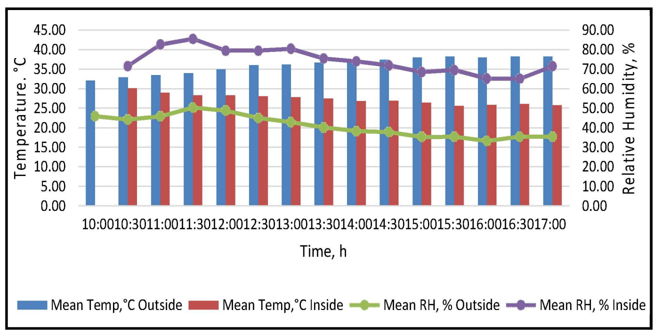


Fig. 2 : **Variation in temperature and RH outside and inside the storage chamber**

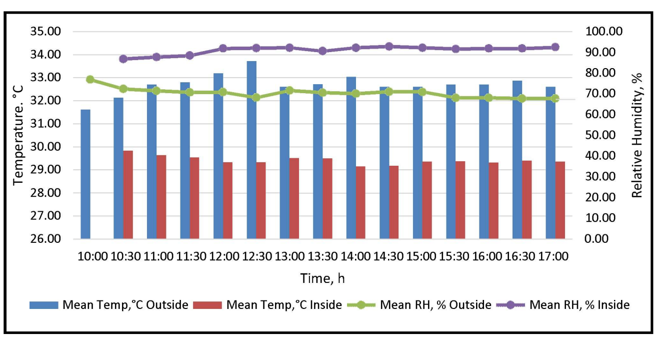


Fig. 3: **Variation in temperature and RH outside and inside the storage chamber**

Physiological loss in weight :

Physiological loss in weight of vegetables in control

Table 1: Physiological losses in weight of vegetables

Name of vegetable	Physiological loss in weight		Difference in weight loss overcontrol (%)	% saving inPLW
	Control (%)	Vending cart (%)		
Fenugreek	1.32	0.92	0.40	30.30
Spinach	2.48	0.93	1.55	62.5
Tomato	1.1	0.47	0.63	57.27
Brinjal	3.45	1.60	1.85	53.62
Bottle Gourd	1.19	0.73	0.43	36.13
Chilly	1.42	0.97	0.45	31.69
Cucumber	1.52	0.73	0.79	51.97

versus in the cart, gain loss over control and per cent saving by the cart given in Table 1. It is seen that physiological loss in weight was quite low (14%) with use of the vending cart as compared to control (38% - 70%). Per cent saving in physiological loss in weight was highest (62.5%) in spinach, followed by tomato (57.27%), brinjal (53.62%), cucumber (51.97%), chilly (31.69%), and fenugreek (30.30%).

Low temperature and higher relative humidity inside the cart helped to slow down the loss of water, which in turn resulted in saving in loss of weight of vegetables. The gain in losses were more than 0.14kg.kg^{-1} of vegetables over control. The saving in loss of weight of vegetables, in turn economic beneficial to vendors. The developed cart can be useful to reduce losses at retailer level and can become a part of cool-chain technology. The cart is can also be used for fruits as the physiology of fruits is same as vegetables.

Conclusion:

The developed solar-powered eco-friendly vending cart equipped with two-stage cooling system maintains low temperature and high relative humidity inside storage chamber as compared outside condition, that retards loss of water from vegetables and preserve vegetables for longer period of time. The indirect-direct type cooling system of the cart was powered by solar energy with battery backup to operate in off-sun shine hours. The cart useful to reduce loss of weight of vegetables, which in turn economic beneficial to vendors. The saving in physiological loss in weight was observed above 30 percent. The developed cart can become a part of cool-chain technology. The cart is can also be used for fruits as the physiology of fruits is same as vegetables *i.e.* high water content and soft texture.

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