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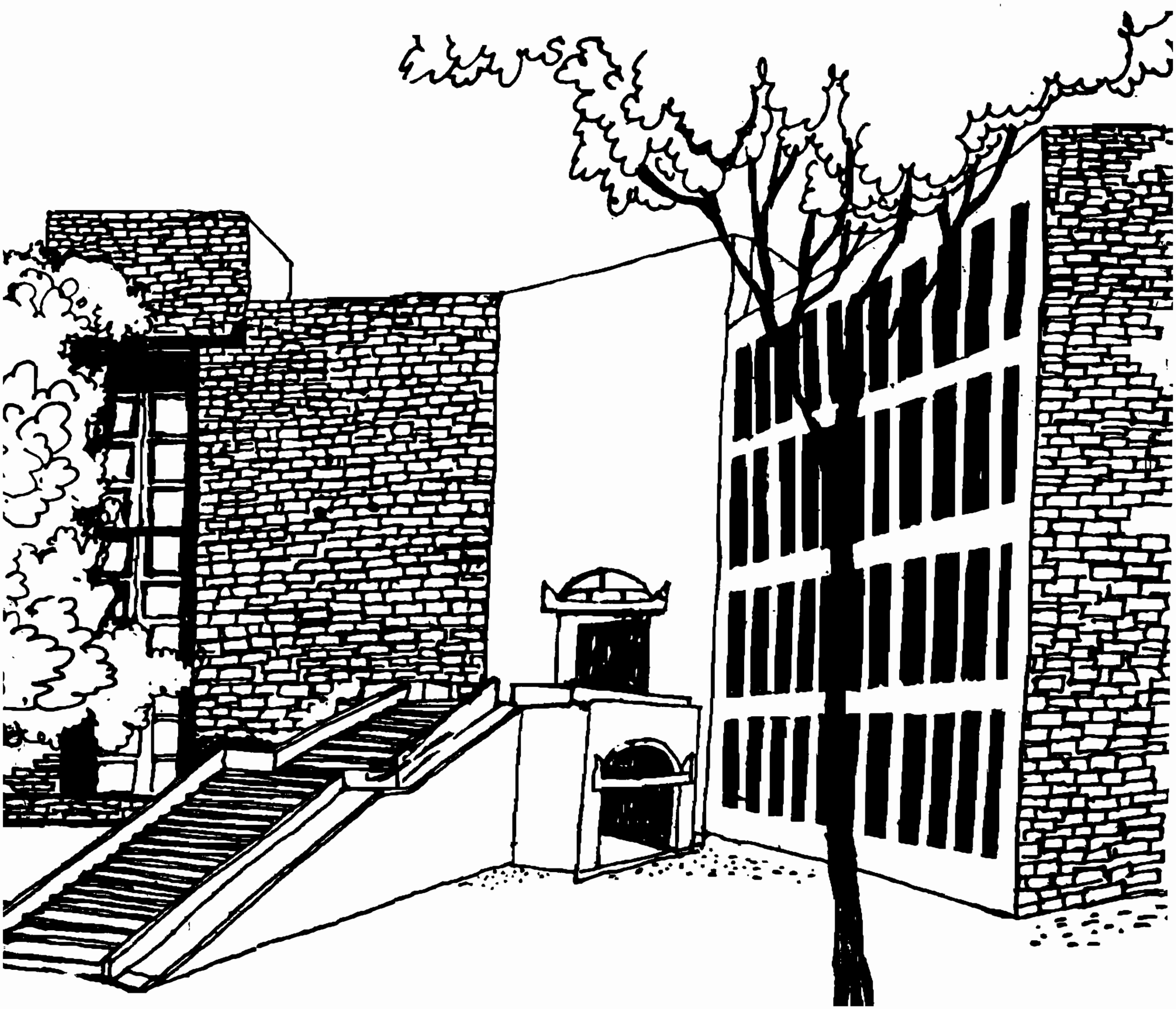

TEMPERATURE DISTRIBUTION IN A TOMATO CARTON

By

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Temperature Distribution in a Tomato Carton

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Abstract

In this write-up, we present an analysis of temperature distribution in tomato carton using finite difference approximation. When freshly harvested tomatoes are placed in a rectangular heap, in a surrounding of 35°C temperature, the temperature in the center of the heap is about 2.5°C higher than outside. The size of heap considered is equal to that typically contained in a 20 kg carton. When the heap is contained in a carton of cardboard, the difference rises to 4°C, and to 5°C, in case of wood. Eight holes, of 20 mm diameter each, are needed to ventilate the carton adequately.

Introduction

Long distance transport of tomatoes continues to be in crudely made wood cartons despite the fact that these are unable to provide sufficient protection against mechanical hazard encountered in transit and handling. Of late, growers in Gujarat are purchasing cardboard cartons meant for such item as cold drinks, biscuits, cosmetics, TVs, etc. and are using these to transport tomatoes. Not designed for fresh biological material, these do not have provision for aeration. Walls of these cartons are not strong enough, for the material these were expected to contain do not exert lateral pressure as say tomatoes and other flow-able material will do. But the practice suggests that the growers are looking for a better substitute. There is need to introduce in the market cartons expressly designed for fresh produce. Work reported in this paper is being done in pursuit of this objective.

A properly designed produce carton must protect the produce from mechanical damage and adverse environmental conditions during handling and distribution. It should have sufficient stacking strength and be capable of maintaining its own structural rigidity during transport. Produce carton should have sufficient ventilation to remove excess heat generated due to respiration. In this paper, this latter aspect is examined. In particular, we determine the steady state temperature distribution in a rectangular heap of freshly harvested tomatoes when placed in a surrounding of constant temperature. Temperature profile is also determined when tomatoes are placed in a carton and when placed in bulk form in a truck carrier. Finally the ventilation requirement for cartons is determined.

Tomatoes continue to respire all along the post-harvest phase. Respiration is the process of internal consumption of organic substance. The end products are CO_2 , H_2O and energy in the form of heat as well as ATP.

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6CO_2 + 6\,H_2O + \text{Energy (Heat and Energy of ATP)}$$

Rate of respiration is known to increase with temperature and is also effected by factors like the composition of gas in the surrounding. Rate may double or treble for every 10^0 C rise in temperature **[1]**. Heat produced by freshly harvested tomato is given in **table 1 [2]**. Tomato grown in Gujarat begins to arrive in the market from the middle of November and continues on till end of February. Day temperatures in these months can vary from 20°C to 35°C. Measured values of heat generated at temperature higher than 25°C are not readily available. In the analysis below, we will assume that the heat generated at 35°C will be twice the value at 25°C.

Plan of Analysis

Analysis will be done in the following steps. First, we will consider that freshly harvested tomatoes are put in a heap, without a container. Steady state spatial distribution of temperature will be determined using finite difference approximation. Next, the same procedure will be followed to compute temperature distribution when tomatoes are put inside a carton of wood and cardboard. Third, we will determine temperature distribution in a heap of the shape and size of a truck carrier, as when the produce is transported in bulk. Finally, we will compute the ventilation requirement in cartons.

Case 1 : Rectangular heap of freshly harvested tomato

Consider that a quantity of freshly harvested tomato has been arranged in a rectangular heap (**figure 1**). Heap is placed in a surrounding of constant temperature. Size of the heap is identical to that of a typical carton carrying 20 kg of produce.

Let,

T_a	Temperature of surrounding (°C)
x,y,z	Rectangular coordinates
m,n,k	Node nomenclature in x, y, and z direction
q	Heat of respiration (kcal/hr-m^3)
k_t	Thermal conductivity of bulk tomato (kcal/m-hr-°C)
$T_{m,n,k}$	Temperature of node m,n,k (°C)
ρ_t	Bulk density of tomato (kg/m^3)

The general finite differences approximation equation is **[3]**.

$$\frac{T_{m+1,n,k}+T_{m-1,n,k}-2T_{m,n,k}}{(\Delta x)^2}+\frac{T_{m,n+1,k}+T_{m,n-1,k}-2T_{m,n,k}}{(\Delta y)^2}+\frac{T_{m,n,k+1}+T_{m,n,k-1}-2T_{m,n,k}}{(\Delta z)^2}+\frac{q}{k_t}=0 \quad \text{.....(1)}$$

Following values have been used in computation.

Ta	35°C, constant
q	162 kcal/hr-m^3
k_t	0.0496 kcal/hr-m°C

Size of heap	420 x 300 x 280 mm
ρ_t	672 kg/m^3

Figure 2 shows the nodes for which the temperatures have been computed. Temperatures at these nodes are summarised in **table 2**. It is seen that the temperature at the centre of the heap would be about two and half degree higher than the surrounding air when steady state has been reached.

Case 2: Tomato in Carton

Consider now that the same quantity of tomatoes has been packed in a rectangular carton. We use resistance concept for writing the heat transfer between nodes **[3]**.
Gauss-Siddle equation,

$$T_i = \frac{q_i + \sum_j (T_j / R_{ij})}{\sum_j (1/R_{ij})} \qquad \text{......(2)}$$

where,

i	Node of interest
j	General conduction node
R_{ij}	Internal node resistance for different coordinate system (hr-°C/kcal)
k_c, k_w	Thermal conductivity of CFB and wood respectively (kcal/m-hr-°C)
q_i	q x v (kcal/hr)
	v = volume of box (m^3)

Following values have been used in computation.

T_a	35°C, constant
q_i	5.76 kcal/hr
k_t	0.0496 kcal/hr-m-°C
Size of box	420 x 300 x 280 mm

	with 5 mm thickness of carton material
k_c	0.052 kcal/hr-m-°C
k_w	0.132 kcal/hr-m-°C

Temperatures were calculated for both CFB and wood carton. Results are presented in **table 3**. It is seen that the temperature at the centre when CFB carton is used, is 4.5°C higher than the surrounding. When wood carton is used, the difference is 5°C. Larger layer differences are due to extra resistance to heat flow offered by the carton walls.

Case 3: Large Rectangular Heap as in Bulk Transport Truck

When produce is transported in bulk, it takes the form of a rectangular heap placed in a truck carrier. Consider that a quantity of freshly harvested tomatoes are put in bulk in a truck with a carrier size of 4 x 2 x 1.5 m. As before, we will consider the temperature of the surrounding as constant (35°C). ***Equation 1*** is employed for calculation. The values used in computation are the same as before except the size of heap.

Temperature at the centre would now be around 11°C higher than the surrounding temperature (**table 4**). In actual practice, tomatoes are transported not in bulk but in wood cartons stacked in six high columns. Although, individual cartons have aeration vents, those are often blocked due to tight placement. In this situation, temperature in the central cartons can be expected to be even higher than 11°C due to the fact that carton walls will impede heat flow as seen in earlier. This is an important result. For it suggests that not only the cartons should have adequate ventilation, but that when loaded in a truck, it must be ensured that vents do not get blocked.

Ventilation Requirement

Equation 3 gives the air flow required to remove a given amount of heat **[2]**.

$$Q = \frac{H}{(C_{f1})\,(C_p)\,(\rho_a)\,(T_i - T_o)} \qquad \ldots\ldots(3)$$

where

Q	Air flow removed (m^3/hr)
H	Heat removed (6.68W)
Cp	Specific heat of air at constant pressure (1 KJ/kg°k)
ρ_a	Density of standard air (1.2 kg/m^3)
C_{f1}	Conversion factor (0.028)
T_i - T_o	Inside and outside temperature difference i.e. 4°C (277°K)

Substituting the values,

$$Q = \frac{6.68}{(0.028)\,(1)\,(1.2)\,(277)}$$

$$= 0.7177\ m^3/hr \qquad \text{or}$$

$$= 0.422\ ft^3/min$$

Hall **[4]** developed following equation to compute flow rate of air through a mass of corn cobs. fWe will employ this for this analysis and assume that pressure drop in a bed of tomatois similar to that of corn-caps.

$$Q = \frac{303\,A\,(\Delta P)^{0.442}}{(L)^{0.540}} \qquad \ldots\ldots(4)$$

where

A	Area perpendicular to the wind through which the air passes (ft^2)
Q	Rate of air flow (ft^3/min)
L	Length of path through the material (ft)
ΔP	Mean pressure difference (inch of water)

The amount of area needed to permit given quantity of air to flow through the material due to natural ventilation is,

$$A = \frac{Q(L)^{0.540}}{303\,(\Delta P)^{0.442}} \qquad \text{......(5)}$$

$$\Delta P = Cp \times 0.19 \times 0.00256\, w^2 \qquad \text{...... (6)}$$

where

Cp Pressure coefficient for rectangular body (1.0)

w Wind speed (2.48 miles/hr)

So,

$$\Delta P = 1.0 \times 0.19 \times 0.00256 \times (2.48)^2$$
$$= 0.003 \text{ inch of water}$$

Now putting all values in ***equation5***

$$A = \frac{0.422\,x\,(2)^{0.540}}{303\,(0.003)^{0.442}}$$
$$= \frac{0.422\,x\,1.45}{303\,x\,0.0767}$$
$$= 0.0263\,ft^2 \ or$$
$$= 24.47\,cm^2$$

Usually produce cartons have holes of dia 15 to 20 mm. We will choose the latter. So the number of holes needed is

$$n = 24.47\,x\,\frac{4}{(d)^2\pi}$$
$$n = 24.47\,x\,\frac{4}{(2)^2\pi}$$
$$n = 7.79\ NOS \approx 8\ NOS$$

In order that the holes do not weaken the carton excessively, the ASTM stipulates that the vent area should not exceed 5% of the surface are. These holes will be placed on smaller and longer vertical walls. The area of walls without holes is 4032 cm^2 and the area of holes is 24.47 cm^2 which is far less than 5% (240 cm^2) of total surface area.

Conclusion

1. Due to the heat of respiration, temperatures in the centre of a heap whether in bulk or contained in a carton, is higher than the surrounding. The difference depends upon the size of heap, rate of heat generation due to respiration, thermal conductivity of produce and thermal conductivity of the carton walls.

2. In a rectangular heap of size 420 x 300 x 280 mm temperature at the centre is about two and a half degree higher than the surrounding. Larger the size greater will be this difference. In particular, when the size of heap is equal to that of a typical bulk truck carrier, the difference could be as large as 11°C.

3. When tomatoes are placed inside a carton of typical 20 kg size (430 x 310 x 290 mm), the difference in temperature between the centre of the carton and outside can be 4.5°C and 5°C higher respectively for CFB and wood.

4. Eight holes of 20 mm diameter are required to ventilate the cartons adequately.

5. It is necessary to ensure that when cartons are loaded in a truck vents are not blocked, otherwise the cartons in the core will be subject to temperatures 11°C or more than the surrounding. Prolonged stay in the truck under such condition, will accelerate physiological deterioration.

Table 1 **Heat of Respiration of Tomato at Various Temperatures**	
Temperature *(^0C)*	*Heat produced in 24 hours* *(kcal/ton)*
10	870
15	1630
20	2480
25	2950
Source: *ASHRAE, Handbook Fundamental 1986*	

Table 2
Temperature in Rectangular Heap of Freshly Harvested Tomato

Heap Size	*Portion*	*Node*								
		1	2	3	4	5	6	7	8	9
420x300x280mm	ABCD	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
	$A^I B^I C^I D^I$	36.67	36.80	36.77	36.65	37.37	36.67	36.65	36.80	36.70
	$A^{II} B^{II} C^{II} D^{II}$	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00

Table 3
Temperature in Tomato contained in a Carton

Carton Size and Material	*Portion*	*Node* 1	2	3	4	5	6	7	8	9
C.F.B.	ABCD	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
420x300x280mm	$A^I B^I C^I D^I$	38.09	38.10	38.13	38.04	**39.24**	38.78	38.56	38.25	38.58
5mm thickness	$A^{II} B^{II} C^{II} D^{II}$	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
WOOD	ABCD	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
420x300x280mm	$A^I B^I C^I D^I$	38.85	38.96	38.97	38.93	**40.15**	38.18	38.25	38.13	38.36
5mm thickness	$A^{II} B^{II} C^{II} D^{II}$	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00

Table 4
Large Rectangular Heap as in Bulk Transport Truck

Heap size (mm)	Portion	Node 1	2	3	4	5	6	7	8	9
4000 x 2000 x 1500	ABCD	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
	A'B'C'D'	45.05	45.75	45.00	45.97	46.18	45.19	45.72	45.85	45.87
	A"B"C"D"	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00

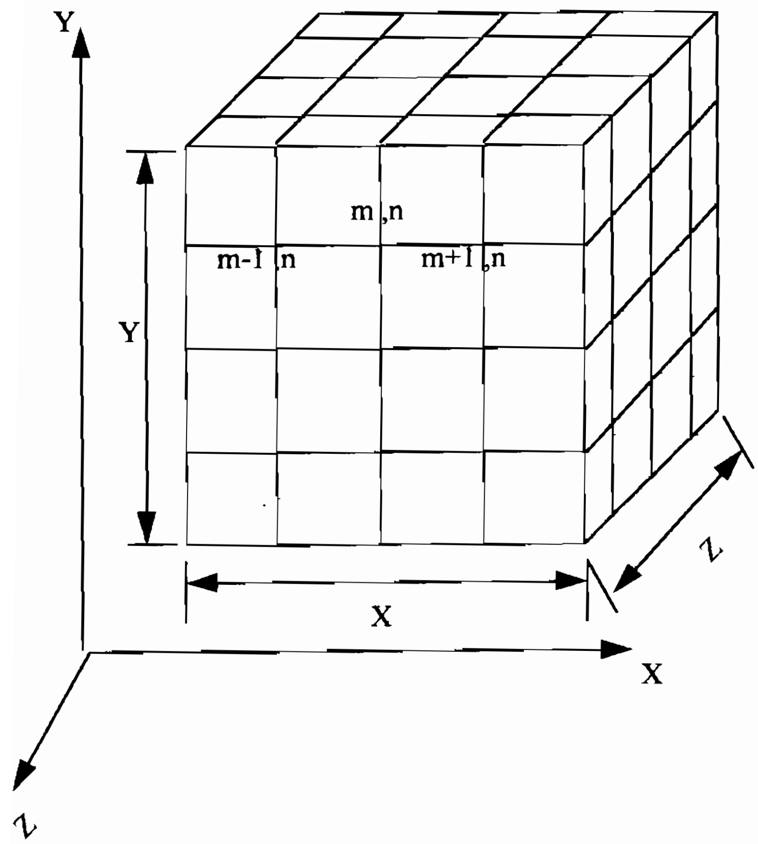

Fig-1 Nomenclature diagram

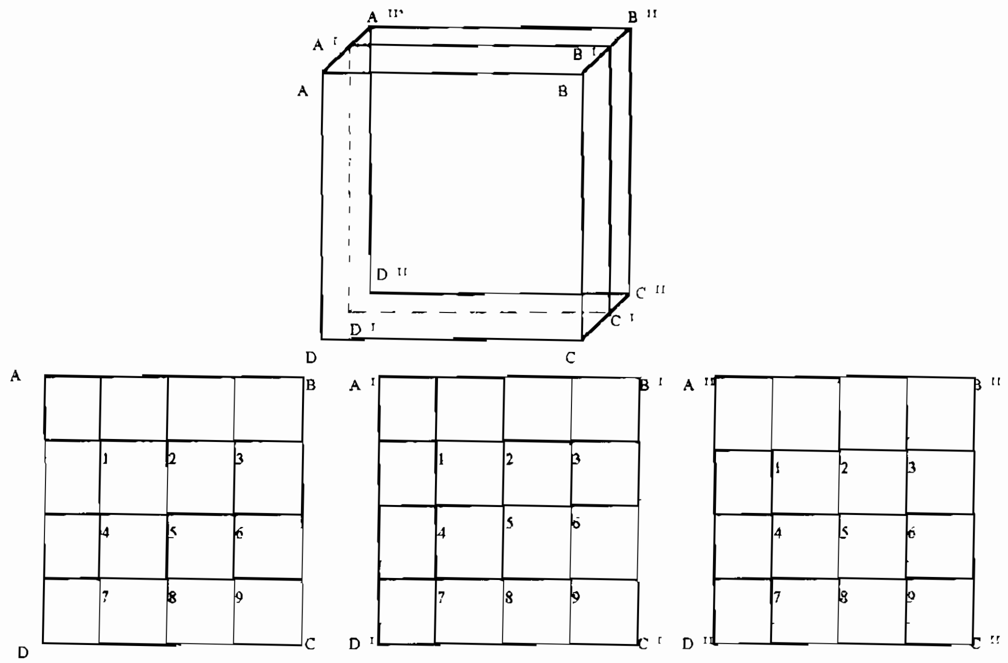

Fig 2 Temperature at different noder at centre and boundry of rectangular tomato heap

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