

DEVELOPEMENT OF A MULTIPURPOSE COLD STORAGE DESIGN SOFTWARE MCS_BCKV v.1.14.1.

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Abstract

The paper proposes development of an interactive, flexible and user friendly software for designing a multipurpose cold storage in Visual Studio Express Desktop2012 environment and evaluation. The developed software--- "MCS_BCKV" has a criterion for typical load estimation and designing of cold storage, selection of evaporator, compressor and condenser in developing country. Load estimating and designing through computer automation is likely to make a positive impact in the dynamic nature of cold storage applications.

Keywords : Multipurpose Cold Storage;Cooling Load; Ventilation Load; Design Software; Respiration Load; Compressor.

Nomenclature:

Q_s = amount of heat transfer through structure, W

A = area of outside wall or inside wall or roof or floor, m^2

ΔT = temperature difference between outside and inside condition

U = overall heat – transfer coefficient, W/m^2K

h_i = convective heat – transfer coefficient of outside, W/m^2K

h_o = convective heat – transfer coefficient of inside, W/m^2K .

ΔX = thickness of layers (it may be wall, roof, floor, insulator, plasteretc), m ,

A_i, A_m, A_o = inside, mean. outside evaporator tube surface area, m^2

K = thermal conductivity of the material, W/mK

Q_p = heat load from the product, W

m = mass of the product, K_g

C_p = specific heat of the product, J/K_gK

A_e = Area of evaporator, m^2

ΔT = temperature difference

Q_{design} = Design load of cold storage, KW

Q_v = heat load for ventilation, W

ΔT_m = Log mean temperature difference

n = number of air exchange

U_e = overall heat – transfer coefficient, W/m^2K

ρ = density of air, K_g/m^3

Δx = thickness of metal wall, m

H_0 = outside enthalpy, KJ/K_g

f_r = refrigerant side heat transfer coefficient

H_i = inside enthalpy, KJ/Kg	f_c = conductance of condensate layer, W/m^2K
Q_i = infiltration load, W	K = thermal conductivity of the material, W/mK
D_h = door height, m	d = outside tube diameter, m
ρ_o = density of outside air, Kg/m^3	A_c = Area of the condensor, m^2
W_b = Wattage of individual bulb, W	A_d = Area of door, m^2
ρ_i = density of inside air, Kg/m^3	Q_{design} = Design load of cold storage, KW
H_0 = outside enthalpy, $\frac{KJ}{Kg}$	h_g = specific heat of respiration, J/Kg
H_i = inside enthalpy, KJ/Kg	ΔT_m = Log mean temperature difference
Q_f = heat load from fans, W	r_2 = outer pipe radius of condenser, m
N_f = Number of fan used in the cold storage	r_1 = inner pipe radius of condenser, m
W_f = Wattage of each fan, W	Q_r = respiration load, W
Q_b = heat load from bulb, W	L_s = stroke length, m
N_b = Number of bulb	K = thermal conductivity of the material, W/mK
UF = use factor (0.5 for industry)	d_c = outer diameter of condenser, m
AF = allowance factor	L = Length of the condensertube, m
m = mass flow rate, kg/s	w = specific work, kJ/kg
γ = compression ratio	P_d = discharge pressure, P_a
v_s = specific volume, $\frac{m^3}{Kg}$	D = bore diameter, m
V_p = Piston displacement per cylinder, $\frac{m^3}{min}$	N = rpm
U_c = overall heat transfer coefficient of condensor, $\frac{W}{m^2K}$	
h_i = inside heat transfer coefficient of condenser, W/m^2K	
h_o = outside heat transfer coefficient, W/m^2K	

1. INTRODUCTION:

Traditionally, load estimation and designing a multipurpose cold storage is done either by manual calculation or judgmental estimation based on experience of the cold storage practitioner. While manual calculation is laborious, estimate based on judgment is liable to error due to gigantic, complex and dynamic nature of present day architectural designs. Load estimating and designing through computer automation is likely to make a positive impact in the dynamic nature of cold storage applications. CFD simulation of coupled heat and mass transfer through porous foods during vacuum cooling process was studied by Sun D. W. and Hu Z. (2003). Simulation of transport phenomena during natural convection cooling of Bagged potatoes

in cold storage is given by Chourasia et.al.(2006). CFD model of the airflow, heat and mass transfer in cool stores was studied by Nahor et.al (2005).And simulation of effect of stack dimensions and stacking arrangement on cool down characteristics of potato in a cold store by computational fluid dynamics is also done by Chourasia et.al. (2007). Software development for cooling load estimation by CLTD method was given by T. Ahmed (2012).From different simulations and modeling an algorithm for design of cold storage can be developed easily.

2.MATERIALS AND METHODS:

2.1. Design Consideration:A cold storage system mainly consists of insulated building structure and refrigeration machinery. The design dimensions and refrigeration load of cold storage can be calculated as—

2.1.1. Heat load of wall, ceiling and floor (building load):

Building load can be calculated from the equation (Arora, 2009):

$$Q_s = UA\Delta T$$

$$\frac{1}{U} = \frac{1}{h_i} + \sum_1^n \frac{\Delta X}{K} + \frac{1}{h_o}$$

2.1.2. Heat gain from product:

$$Q_p = mC_p\Delta T$$

2.1.3 Ventilation load:

$$Q_v = n\rho V(H_o - H_i)$$

2.1.4. Infiltration load: $Q_i = 1.33 \times A_d \times \sqrt{D_h \{1 - (\rho_o - \rho_i)\}} \times (H_o - H_i)$

2.1.5. Fan load:

$$Q_f = N_f \times W_f$$

2.1.6. Bulb load: $Q_b = N_b \times W_b \times UF \times AF$

2.1.7. Heat load for labor working: $Q_l = N_l \times W_l$

2.1.8. Total heat load of the cold storage:

$$Q_{tot} = Q_s + Q_p + Q_v + Q_i + Q_f + Q_b + Q_l$$

$$Q_{design} = Q_{tot} / S.F.$$

$$Q_{design} = \left(Q_{design} / 3.5167 \right) \text{ TR}$$

2.1.9. Design of Evaporator: The design steps of evaporator required the knowledge of cooling load (Q_{design}). The following steps are needed for design of evaporator:

2.1.9.1. Surface area of evaporator:
$$A_e = \frac{Q_{design}}{(\Delta T_m U_e)}$$

$$\frac{1}{U_e} = \frac{1}{f_r} + \frac{\Delta x A_i}{K A_m} + \frac{1}{f_c} \frac{A_i}{A_o}$$

2.1.9.2. Length of the pipe: After knowing the surface area of the evaporator, the pipe length, L_p

$$L_p = \frac{A_e}{\pi d}$$

2.1.10. Design of condenser: Design steps for condenser are as follow

2.1.10.1. Area of the condenser:
$$A_c = \frac{Q_{design}}{(\Delta T_m U_c)}$$

$$\frac{1}{U_c} = \frac{r_2}{r_1 h_i} + \frac{r_2}{K} \ln \frac{r_2}{r_1} + \frac{1}{h_o}$$

2.1.10.2. Length of the tube:

$$L = \frac{A_c}{\pi d_c}$$

2.1.11. Compressor design:

2.1.11.1. Power consumption:

$$W = m \times w$$

$$w = \frac{\gamma}{\gamma - 1} p_s v_s \left[\left(\frac{p_d}{p_s} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

2.1.11.2. Stroke & bore of the compressor:

$$V_p = \frac{\pi D^2}{4} L_s N$$

2.2. Software development:

The computer program requires different input parameters such as product selection from a panel, storage capacity, specific storage density, height of the chamber, length of the chamber, number of chamber, selection of insulation, product load per day, indoor and outdoor air condition, air ventilation, equipment's and occupants. With this input one can run the software very carefully which give absolute output to the user.

2.2.1. Calculation of dimensions and layout area of structure: At first the program will ask the user to select the products to be stored and capacity of the multipurpose cold storage. (Fig-1). Then click next button to proceed.



Fig-1: Software Interface (MCS_BCKV)

Then it will ask to state the capacity of the cold storage and product specific density. Supplying relevant storage density data for various fruits and vegetables, the developed program will calculate the design parameters for a multi-purpose cold storage facility.

The volume of the chamber can be calculated from the formula

$$Volume = \frac{capacity(MT)}{specific\ storage\ density\left(\frac{MT}{m^3}\right)}$$

Thereafter, the program asks to input height of the chamber, and number of the chambers. From these data, the program will calculate different dimensions of the cold storage like length and width of chamber, anti-room, pre-cooling room and lay out area of cold storage.(Fig-2)

Fig-2: Dimensional Calculation

2.2.2. Calculation of structural load:

Structural load calculation determines the sensible cooling load due to the heat leakage through ceiling, floor and walls. Here the program will ask the user to choose insulating materials for the structure and structural load can be calculated.(Fig-3)

2.2.3. Calculation of product load:

For calculating the product load, the user has to input the initial product temperature and pull down time (hr).And the software calculates the unsteady state and steady state product load.

Fig-3: Cooling Load Calculator

2.2.4. Calculation of Ventilation and Infiltration load:

For calculate ventilation and Infiltration load we mainly use equation in the program. It includes mainly no. of air exchange, inside and outside air condition.

2.2.5. Calculation of Equipment's load:

For calculation of equipment load of the cold storage through the program will ask the user to input no. of fan, no. of labor working, no. of bulbs and it automatically calculates the equipment load.

2.2.6. Calculation of Design heat load:

From above input data and equations, the program will automatically calculate the design heat load of the cold storage in ton of refrigeration (TR).

2.2.7. Design of Evaporator: The heat transfer area of evaporator can be calculated from corresponding to the estimated refrigeration capacity. The program asks the user to enter the evaporator tube diameters. And it gives the length of tube, fin spacing, evaporator pressure, number of tube per pass.

2.2.8. Design of Compressor:

From the calculated design load the program will calculate the power, stroke and bore length, rpm of the compressor by inputting the number of cylinders.

The screenshot shows a software window titled "Form5" with the heading "Compressor Design". It contains several input fields: "No. of Compressor Cylinder" (value: 2), "Piston Speed(m/s)" (value: 3), "L/D ratio" (value: 1.2), "Compressor Motor Power (HP)", "Dia of Cylinder(mm)", "Stroke Length(mm)", and "Speed of Motor(RPM)". A "Calculate" button is positioned below the input fields. At the bottom, there are three buttons: "<<Back", "End", and ">>Next".

Fig-4: Compressor Design Panel

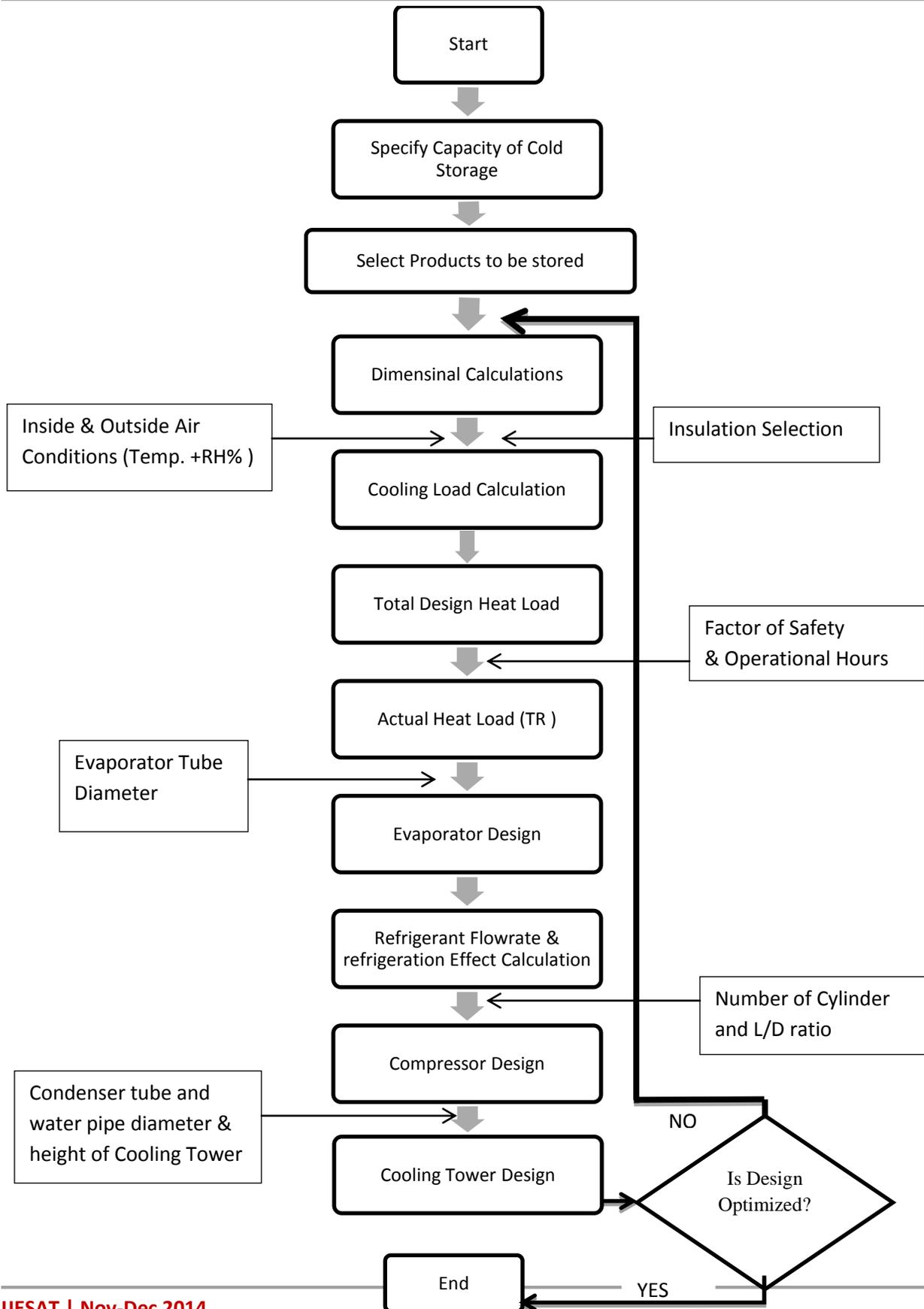
The screenshot shows a software window titled "Form6" with the heading "Design of Cooling Tower". It contains several input fields: "No. of pass or No. of horizontal rows" (value: 4), "Dia of Condenser tube" (value: 0.045), "Dia of Water Tubes" (value: 0.0254), "Temp differential of water" (value: 5), "Height of Cooling Tower", "No. of Vertical rows of condenser tube", "Length of condenser tube in each row", and "Water Pump HP". A "Calculate" button is positioned below the input fields. At the bottom, there are two buttons: "<<Back" and "END".

Fig-5: Cooling Tower Design Panel

2.2.9. Design of Condenser/ Cooling Tower:

The size of the condenser can be calculated using the equations. The program calculates the total heat transfer area of condenser. The program asks the user to input the required number of pass, diameter of water tubes, height of cooling tower for the condenser and the length of the condenser and the water pump power (HP) will be calculated.

2.3. Algorithm for the Software:



3. RESULTS AND DISCUSSION:

In the multi-purpose cold storage, various fruits and vegetables are stored at respective optimum storage conditions. Depending upon the physical properties of agricultural produce, these commodities occupy variable storage space for the same storage capacity. This variation of storage space can be represented by specific storage density. Therefore, the relationships for the design parameters are obtained at varying storage density which could be used for various products stored in multi-purpose cold storage facility.

3.1. Relationship between cooling load and specific storage density of product:

For Storage capacity of 5000Ton, Height of the cold storage: 13.5m, Length of the cold storage: 18.5m, No. of chamber: 4. The relationships between the cooling load and specific storage density for different and mixed type products have found to be linearly proportional. The graphical representation is shown in Fig-6.

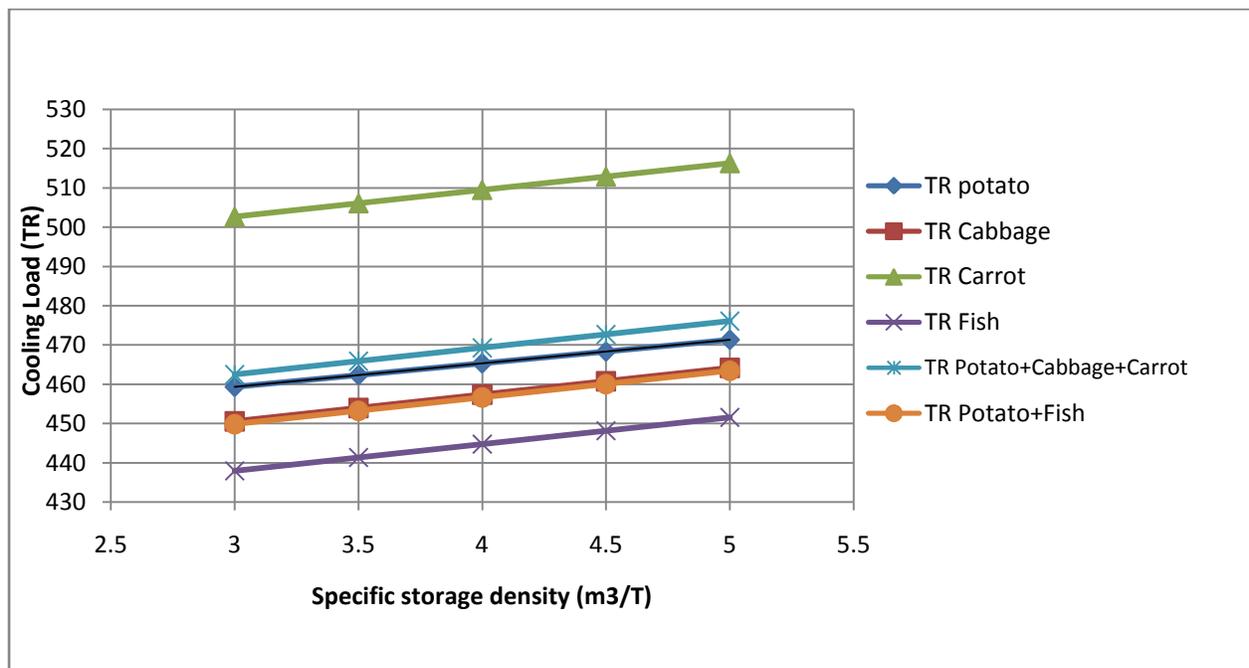


Fig-6: Cooling Load vs. Specific Storage Density Plot

3.2. Relationship between Capacity of Multipurpose Cold Storage and Evaporator System:

For Height of the cold storage: 13.5m, Length of the cold storage: 18.5m, No. of chamber: 4. The relationships between the Storage Capacity (Ton) and Number of Evaporator Tube/Pass for different and mixed type products have found to be linearly proportional. The graphical representation is shown in Fig-7. and Table-1.

Table-1

Capacity(Ton)	Evaporator			
	No. of Tube/Pass			
	Potato	Cabbage	Potato+ Cabbage	Potato + Fish
1000	37	36	37	36
2000	73	72	72	71
3000	109	107	108	107
4000	145	142	144	142

5000	181	177	179	177
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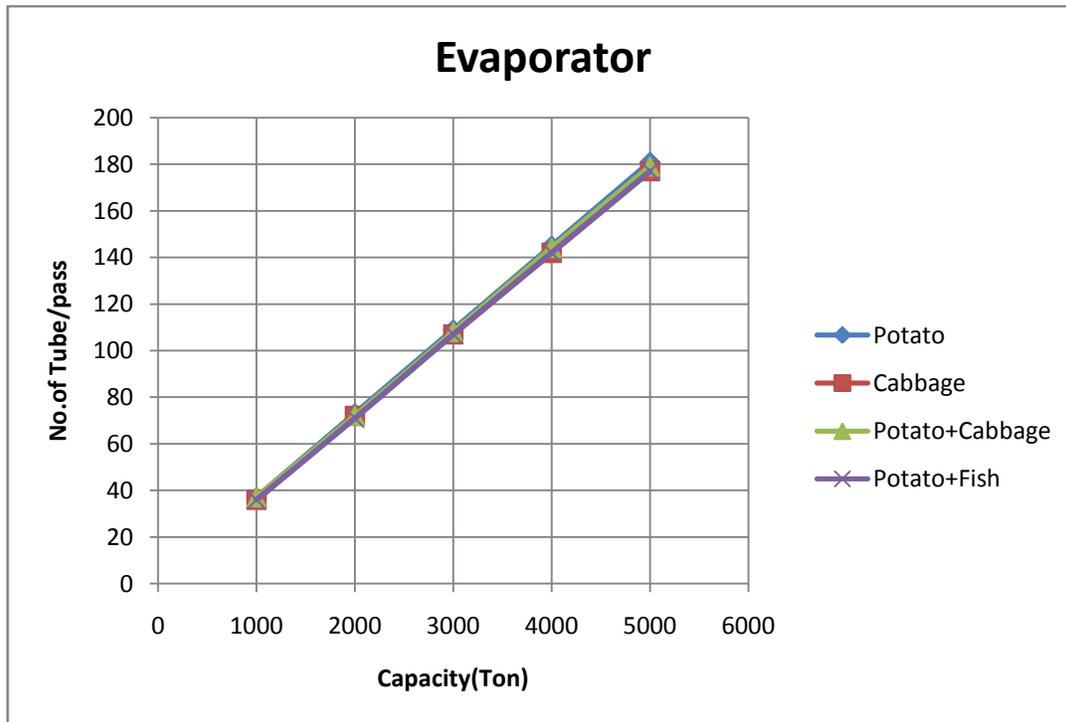


Fig-7:Evaporator Tube vs. Capacity

3.3. Relationship between Capacity of Multipurpose Cold Storage and Compressor System:

For Height of the cold storage: 13.5m, Length of the cold storage: 18.5m, No. of chamber: 4.

The relationships between the Storage Capacity (Ton) and Power of the Compressor (HP) for different and mixed type products have found to be linearly proportional. The graphical representation is shown in Fig-8 and Table-2.

Table-2

Capacity(Ton)	Compressor Power(HP)			
	Potato	Cabbage	Potato+Cabbage	Potato+Fish
1000	63.57	62.38	63.13	62.29
2000	125	122.86	124.35	122.66
3000	186.88	183.33	185.57	183.04

4000	248.5	243.8	246.79	243.42
5000	310.19	304.28	308.02	303.79

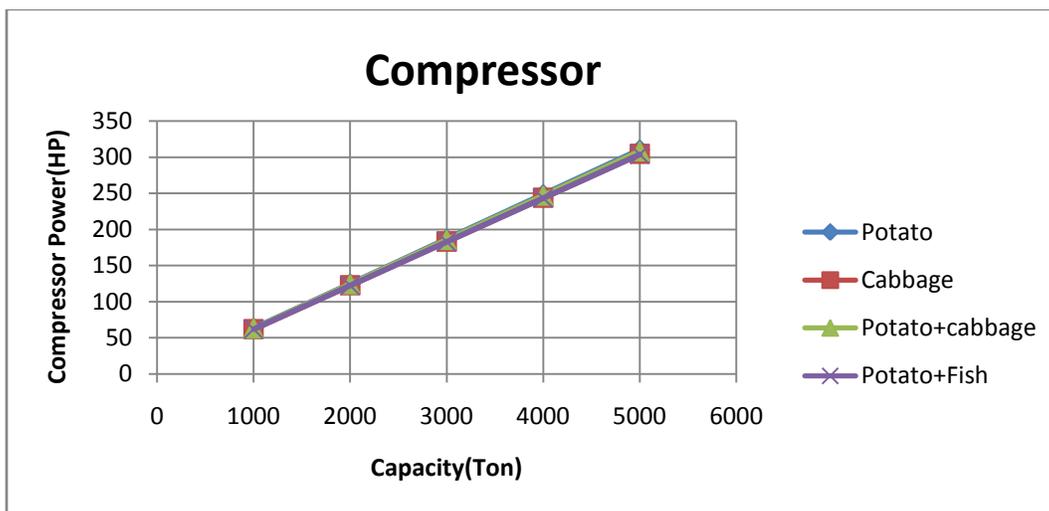


Fig-8: Compressor Power vs. Capacity

3.4. Relationship between Capacity of Multipurpose Cold Storage and Cooling Tower:

For Height of the cold storage: 13.5m, Length of the cold storage: 18.5m, No. of chamber: 4.

The relationships between the Storage Capacity (Ton) and Water Pump Power (HP) of Cooling Tower for different and mixed type products have found to be linearly proportional. The graphical representation is shown in Fig-9. and Table-3.

Table-3

Capacity(Ton)	Cooling Tower			
	Water Pump HP			
	Potato	Cabbage	Potato+ Cabbage	Potato+Fish
1000	6.2	6	6.1	6
2000	12.6	12.3	12.5	12.3
3000	19.4	19	19.3	19
4000	26.7	26.2	26.5	26.1
5000	34.5	33.7	34.2	33.7

From result and discussion we say that all the parameters regarding cold storage designing is mathematically linearly proportional with the storage capacity of cold storage and the specific storage density of product.

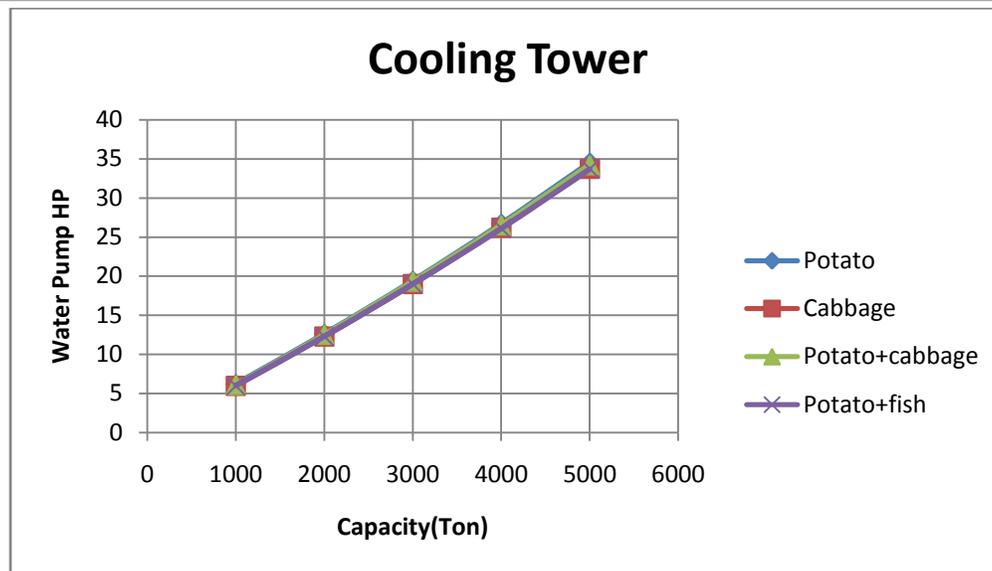


Fig-9: Cooling Tower Water Pump HP vs. Capacity

4. CONCLUSIONS:

To reduce the total cost and optimize the refrigeration capacity, calculation of various design parameters of the cold storage in individual manner is inevitable. To avoid the complexity and repetition of calculation of various dimensions of cold stores for different capacities, development of a suitable computer program has no alternative. To obtain various data from the program from which we can compare relevant parameters needed for choice for the optimum design.

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