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A Simplified Method For Estimating The Peak Load In The Large Cold Stores

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Abstract

In this paper a simplified method for estimating the peak load in the large cold stores is found and its occurrence day by utilizing two new variables A & B. The first variable represents the number of days that is necessary for cooling the product (storage) up to the needed temperature according to the daily temperature differences only. The second variable represents the number of days required for cooling the total product (storage) depending upon the daily storage mass only without returning back to the details of distribution of the daily thermal load that is followed in calculating thermal load for cold stores.

By the demonstrative and analysis of the thermal load in cold stores with detailing study for each effective factors in estimating the thermal load characteristic is observed that the factors daily temperature differences (ΔT) and storage mass (m) per day affect significantly in estimating the peak load values and day of occurrence.

Keywords: Cold store, Peak Load Calculation, Daily Temperature Difference, Daily Storage Mass

طريقة مبسطة لتخمين حمل الذروة في المخازن المبردة الكبيرة

الخلاصة

تم في هذا البحث إيجاد معادلة يمكننا بواسطتها تخمين حمل الذروة و يوم حدوثه في مخازن التبريد الكبيرة وذلك بالاستفادة من المتغيرات دون الرجوع الى تفاصيل توزيع الحمل الحراري .يمثل المتغيرالاول عددالأيام المطلوبة لتبريدالمنتج (الخزين) الى درجة الحرارة المطلوبة طبقاً لفرق درجات الحرارة اليومية فقط، أما المتغير الثاني فيمثل عدد الأيام المطلوبة إعتماداعلى مقدارالخزن اليومي.

تبين من الدراسة أعلاه بأن العاملين فرق درجات الحرارة اليومي وكمية الكتلة المخزونة لكل يوم (ΔT، m)؛ لهما تأثير ملموس في تحديد مقدار حمل الذروة وزمن حدوثه وذلك بعد تحليل ودراسة كل العوامل المؤثرة التي تحدد مواصفات الحمل الحراري في المخازن المبردة الكبيرة.

Nomenclature

A : surface area that heats transfer through it (m^2)

C_p : Specific heat of the product (J/kg.°C)

f_i, f_o : Heat transfer coefficient for the external and internal air layers (W/ m^2 °C

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h_{out} : Enthalpy of the external air (outside condition) (J/kg)
h_{in} : Enthalpy of the internal air (inside cold store condition) (J/kg)
K : Thermal conduction coefficient for materials forming the wall (W/m.°C)
m : Daily storing mass in aday (kg)
m_{Tot}: Total capacity mass storage(kg)
N_L : Number of lighting
N_P : Number of persons
N_m : Number of equipment
NOC: Numbers of the air change per day
OH_m : operating of hours of the equipment per a day
OH_L : Operating hours of lighting per day (hr/day)
OH_P : Hours of work in the day
P_m : Input Power of equipment (W)
P_L : Power of lighting (W)
Q_1 : Heat transfer through wall, roof, and ground (W)
Q_2 : The amount of heat transfer due to the air change (W)
Q_3 : Thermal load from lighting (W)
Q_4 : Thermal load from equipment (W)
Q_5 : Amount of heat from persons (W)
Q_6 : Sensible heat (W)
Q_7 : Amount of heat results from respiration (W)
Q_P : Amount of heat generates from each person (W/person)
q_{res} : Heat respiration (J/kg)
V : daily air change (m3/day)
V_s : Volume of cold store (m^3)
U : over all heat transfer coefficients for wall, roofs and ground (W/m^2. °C)
$\Delta T_{w,r,g}$: Temperature difference between two sides of wall, roof and ground (°C)
ΔT : Daily temperature reduction °C
ΔT_{Tot} : Total temperature differences required (°C)
ρ_{air} : Air density (kg/ m^3)

1. Introduction

Cold stores are vessels or rooms properly thermal insulation supplied by electrical and mechanical machines that decrease the temperature of the space and its contents to a proper temperature thus; this lowered proper temperature reduces or prevents the factors which help to corrupt the storage products. The suitable temperature for storing depends on two main factors; type of the storage and the duration of store [1].

These stores are frequently supplied with cooling equipment, which its capacity reaches thousands of tons of cooling, and other completion equipment that support in works of separate, transfer, pouch and so on. Also the initial cost of the cold stores is very expensive. The cooling system forms a very important part from the total cost, thus the equipment selection is very important and it is a real effective factor upon the total coast of the project.

Jing Xie et al. [2] they used CFD technique to study a two-dimensional mathematical model for the inside a mini type construction cold store (4.5 m × 3.3 m × 2.5 m). The simulation results reflected the characteristics of airflow and temperature distribution, and a several design parameters (corner baffle, the stack mode of food stuffs, etc.) were analyzed. The results of calculation indicated that all these designed parameters influenced the flow and temperature fields.

S. Akdemir [3] studies the cooling load and choosing of cooling system elements for designing of the cold store. He calculated transmissions, infiltration, production, and other source of heat. In addition the amount of the cooling fluid was also calculated.

Erol, N. [4] stated that the determination of total input cooling load would not be possible, for this reason there may be some deviation in the cooling load and the focus point must be minimizing the deviation. He explained that the ambient temperature of cold store, the situation of store product before entering the cold store, the daily working hours and the determination of which product will be stored are important for calculation of the cooling load.

2. Elements of thermal load in the cold stores

The thermal load per day in the cold stores can be divided into two main parts:

2.1 External thermal load

The external thermal load is due to transfer of the heat from external to internal space of the store. It consists of:

2.1.1 Heat transfer through wall, roof, and ground

Can be calculated using the following equation (Searle engineers hand book 1988) [5]:

$$Q_1 = U \cdot A \cdot \Delta T_{w,r,g} \quad \ldots\ldots(1\text{-a})$$

$$1/U = 1/f_i + X_1/K_1 + X_2/K_2 + \ldots X_n/K_n + 1/f_o \quad \ldots\ldots(1\text{-b})$$

2.1.2 **Air change heat gain**

It can be calculated using the following equation [5]:

$$Q_2 = \frac{\rho_{air}.V.(h_{out} - h_{in})}{3600 \times 24} \quad \ldots\ldots (2)$$

(V) Is calculated from the knowledge of store's volume and the number of air change in a day as shown below (Air-Conditioning & Refrigeration Institute 1987) [6].

$$V = V_s.NOC \quad \ldots\ldots(3)$$

2.2 Internal thermal load

This thermal load generated inside the cold store and it contains the following:

2.2.1 Lighting load

It is the thermal energy generated from lighting used inside a store. It can be calculated using the following equation [5]:

$$Q_3 = N_L.P_L.OH_L / 24 \quad \ldots\ldots (4)$$

2.2.2 Equipment Load

The equipment load can be calculated using the following equation:

$$Q_4 = N_m.P_m.OH_m / 24 \quad \ldots\ldots (5)$$

2.2.3 Persons thermal load (workers)

it is calculated using the following equation:

$$Q_5 = N_P.Q_p.OH_P / 24 \quad \ldots\ldots(6)$$

2.2.4 Product (Sensible) thermal load

it is calculated using the following equation:

$$Q_6 = \frac{m.C_p.\Delta T}{24 \times 3600} \quad \ldots\ldots(7)$$

2.2.5 Respiration load

It is the amount of heat generates from product due to the vitality chemical reactions in any plan and it can calculate using the following equation [5]:

$$Q_7 = \frac{m.q_{res}}{24 \times 3600} \quad \ldots\ldots (8)$$

3. Factor affects thermal load

In the revision of the previous thermal loads which are used for design any cold store; it can be noticed that:

- T he internal thermal load forms the larger part of the overall load and the heat from product has a larger part of the internal load (specific heat and respiration heat of potato are 3.56 kJ/kg. °C , 270 kJ/kg and for meat 3.2 kJ/kg. °C , 231 kJ/kg) returning to ASHRAE Handbook 1998 [7]. The other loads take different ratio from overall load.

- It is clear that there are two important factors in calculation of the product load, the daily storing mass (m) and the daily temperature difference ΔT which affect directly in the value of the load, so the wrong selection of those two factors may give a very far result from the actual and then choose incompatible equipment to the real load (expensive unnecessarily cost). The time is taken by the product to reach the optimum storage temperature (sometimes called the pull- down time) will be limited by the overall refrigeration capacity of the equipment (M.Eltawil, D.Samuel and O.Singhal 2006 [8].
- Due to the probability of miss-match of all components loads in one day so it can not be able to find the peak load directly although the correct choice of the daily storing mass and the daily temperature difference was used.

4. Determination of the peak load and starting day

To simplifying the analysis of the calculation, it's important to redefine some variables:

* External load = $Q_1 + Q_2$ (W)
* Base load=$Q_3+Q_4+Q_5$ (W)
* Internal load = $Q_6+ Q_7$ (W)

And two new factors:

*** Factor -A** : It represents number of days necessary for cooling the product (storage) up to the required temperature depending upon the daily temperature differences (Δ T) only i.e. :

$$A = \frac{\Delta T_{Tot}}{\Delta T} \quad \text{(day)} \qquad ....(9)$$

* **Factor -B**: It represents number of days required to fill the store by products depending on the daily storing mass (m) only, i.e. :

$$B = \frac{m_{Tot}}{m} \quad \text{(day)} \qquad .....(10)$$

5. Case Study-Sample of Calculation

Input data

- Dimension: (25 × 15 × 5) m
- Store Room Temperature: 4 °C
- Product : Potato
- Capacity : 550 ton
- Product Initial Temperature : 35 °C
- Outside Temperature : 50 °C & RH= 20%
- Wall U-value : 0.34 $W/m^2.$ °C (for 10 mm Polystyrene board)

Peak load calculation (traditional method)

- Q_1 : Wall & Roof , use equation -1

$$Q_1)_{wall} = 0.34 \times 400 \times (50 - 5) = 6256 \ \text{W/day}$$

$$Q_1)_{Roof} = 0.34 \times 375 \times (50 - 5) = 5865 \ \text{W/day}$$

$$Q_1 = 6256 + 5865 = 12121 \ \text{W/day}$$

- Q_2 : Air change, use equation-2

$$Q_2 = \frac{1.27 \times 2962.5 \times (91 - 15.5) \times 1000}{3600 \times 24} = 3287.7 \ \text{W/day}$$

- Q_3 : Lighting, use equation - 4 (operating hour = 10)

$$Q_3 = 10 \times (15 \times 25) \times 10 / 24 = 1562.5 \ \text{W/day}$$

- Q_4 : Equipment, use equation- 5 (fan power 4×3 kW & heater of 8 kW)

$$Q_4 = 20 \times 1000 \times 18 / 24 = 1500 \ \text{W/day}$$

- Q_5 : Person, use equation - 6 (operating hour = 10)
  $Q_3 = 10 \times 240 \times 8 / 24$
  = 800 W/day
- Q_6 : Product(sensible), use equation - 7 (Cp of product= 3.56 kJ/kg. °C)

$$Q_6 = \frac{550\times10^3 \times 3.56\times10^3 \times (35-4)}{24\times3600}$$

= 702523 W/day

- Q_7 : Respiration(latent), use equation - 8

$$Q_7 = \frac{550\times10^3 \times 270\times10^3}{24\times3600}$$

= 1718750 W/day

Table -1 shown the summary of calculation

<u>Load calculation with ΔT and Δm</u> (new method)

- Let ΔT per day = 2 °C
  Therefore number of days required (Factor- A) = (35-4)/2 = 15.5 day
- Mass charging per day (m) = 110 ton
  Therefore number of days required (Factor- B) = 550/110 = 5 day
- Load calculation
  Q_1=0.34×2× (400+375) (where ΔT=2 °C)
  = 527 W

$$Q_2 = \frac{1.27\times2962.5\times4.87\times1000}{3600\times24}$$

= 212 W

Q_3, Q_4, Q_5 same as before
Q_6 using equation-7 and equation-8, with ΔT=2 °C and m=110 ton

$$Q_6 = \frac{110\times10^3 \times 3.56\times10^3 \times 2}{24\times3600}$$

= 9064.8 W

$$Q_7 = \frac{110\times10^3 \times 270\times10^3}{24\times3600}$$

= 343750 W

6. Daily load distribution Curves

A collection of different cases of storing were taken depending upon storing masses and the daily temperature difference which covered most of the expected states in the loads of cold stores. Table -2 shows those chosen cases and the two factors A and B.

Figures (1) to (5) represent the distribution of the daily load during the first period of storing for cases in the Table-2.

7. Results and Discussion

The graphical analysis and study of the load component distribution of previous figures could build Table-3 which represents a summary of the obtained results and offers simple equations to calculate peak load for the most cases without returning back to the details of loads distribution or graphical analysis or backup figures that is required to calculate throughout the first days of storing reaching to last days with algebraic sum to determine the peak load and day of it.

In general, these are the obtained simplified equations

Peak load = Base Load + External oad + B×Q_7 + minimum of (A or B) ×Q_6

Peak load Day = maximum of (A or B)

In order to verify the validity of the above equation, it can be applied on the case study example

- Base load= $Q_3 + Q_4 + Q_5$ = 17.36 kW/day
- External load = $Q_1 + Q_2$ = 15.41 kW/day
- B × Q_7 = 5 × 343.7 = 1718.5 kW/day
- Min(A, B) × Q_6 = 5 × 9.05 = 45.3 kW/day

Total load = 17.36 + 15.41 + 1718.5 +45.3 =1796.57(kW/day) and the peak load day is 20.

The result of the total peak load above is about 1796 kW/day, whenever, the peak load calculated with traditional method listed in table-1 is 2454 kW/day. i.e. the actual peak load (suggested) is about 26% less than the other (traditional).

From Table-3 and figures (1) to (5), in some cases it appears that peak load duration might not be exceeded more than one day and then reduced gradually, that means the possibility to pass (avoid) this period of highly load in this day by changing the storing method. Table-3 enables the store manager or staff to determine previously the value and time of peak load to take the necessary technical arrangements.

The final peak load equation shows that the last term is the major factor affected on the result of the peak load calculation therefore the relation between 1/A or $\Delta T/\Delta T_{Tot}$ and 1/B or m/m_{Tot} can be plotted against the increasing in the load as a percentage of product load (Q_6), as shown in figure (6).

Figure (6) shows the increasing of 1/A (increases the ratio of daily temperature difference to the total of temperature difference($\Delta T/\Delta T_{Tot}$)causes increasing the peak load while the value of 1/B is constant until it reaches its maximum value when A=B. As mentioned above the load ratio increases when 1/B is significantly increased with constant value of 1/A.

In general, the peak load will decrease (practically is preferable) when the value of A and B is large; if there are no technical limitations.

7. Conclusions

The result of applying the present prediction method of peak load estimation reveals the significant difference between the two method of calculation and the probability of wrong estimation of the load in large cold stores which causes a loss of money by choosing over size machine to overcome the load due to the overestimate of the cooling load.

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Table (1) Summary of load calculation

Q	Load type	kW/day
1 2	External Load	12.121 3.29
3 4 5	Base Load	1.56 15.0 0.8
6 7	Internal (Product) Load	702.5 1718.7
TOTAL		2454

Table (2) The chosen cases for percentage of the daily storing mass and the temperature difference

Case	$\Delta T/\Delta T_{Tot}$ %	Factor-A (day)	m/m_{Tot} %	Factor-B (day)
1	25	4	10	10
2	10	10	25	4
3	50	2	50	2
4	33	3	10	10
5	20	5	50	2

Table (3) A summary of the result

case	**Peak load day**	**Nominal load starting day**	**Peak load (W)**	**Nominal Load (W)**
A=B	A or B	A+B	Base load + External Load + $B*Q_7+A*Q_6$	Base load + External Load + $B*Q_7$
A>B	A	A+B	Base load + External Load + $B*Q_7+B*Q_6$	Base load + External Load + $B*Q_7$
B>A	B	A+B	Base load + External Load + $B*Q_7+A*Q_6$	Base load + External Load + $B*Q_7$

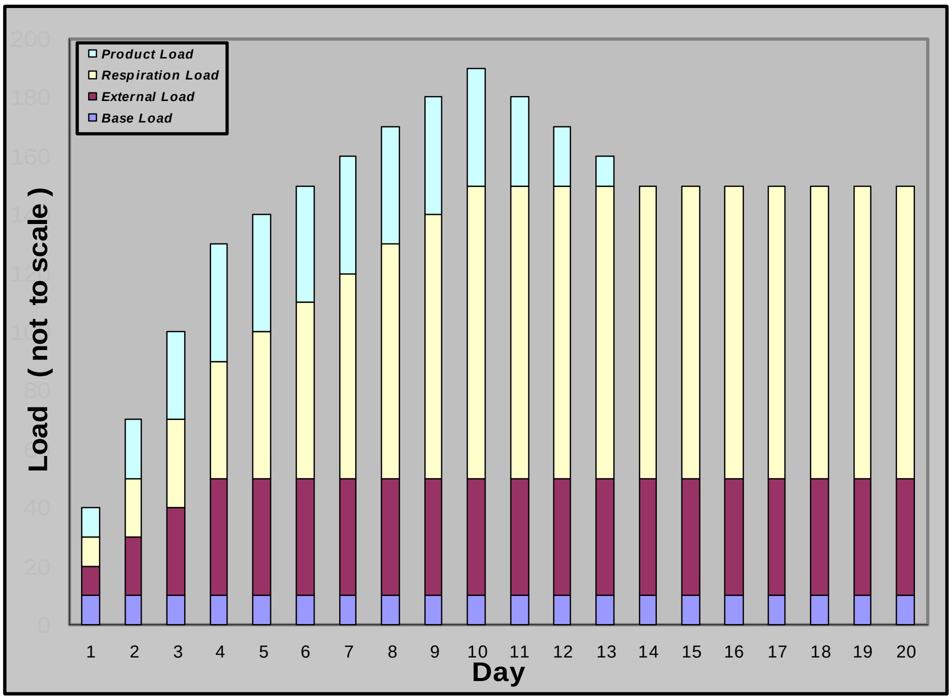

Figure (1) Load distribution case No. 1 (A= 4 , B= 10)

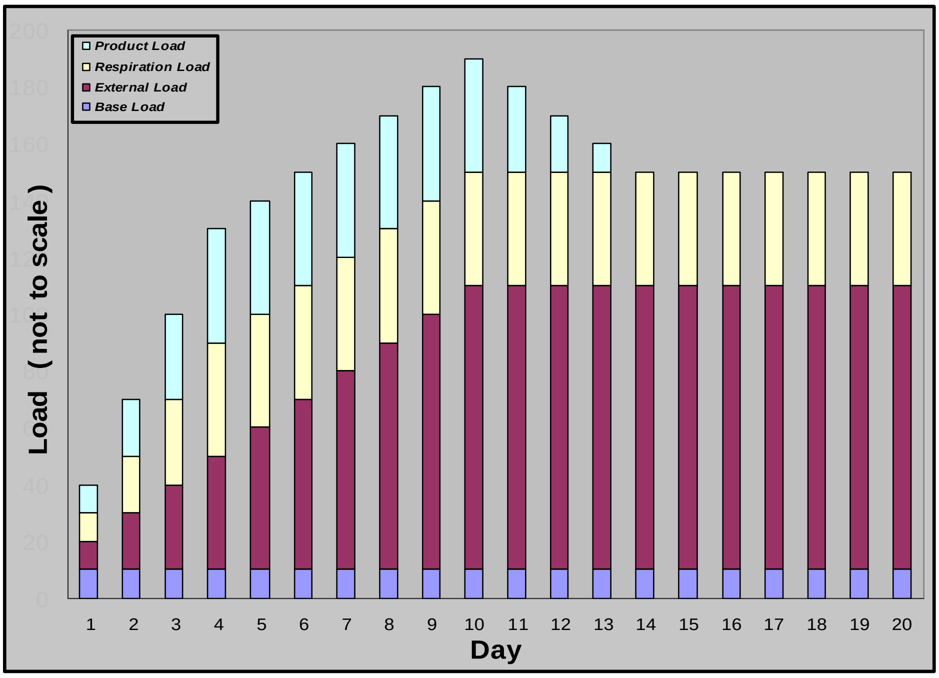

Figure (2) Load distribution case No .2 (A=10, B=4)

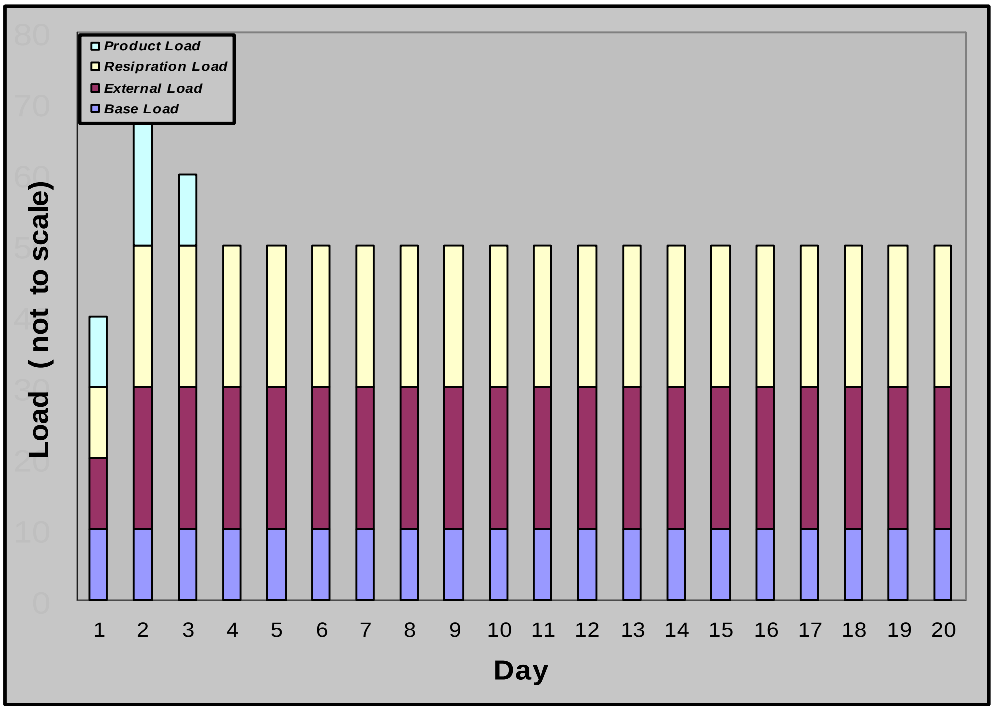

Figure (3) Load distribution case No. 3 (A=2, B=2)

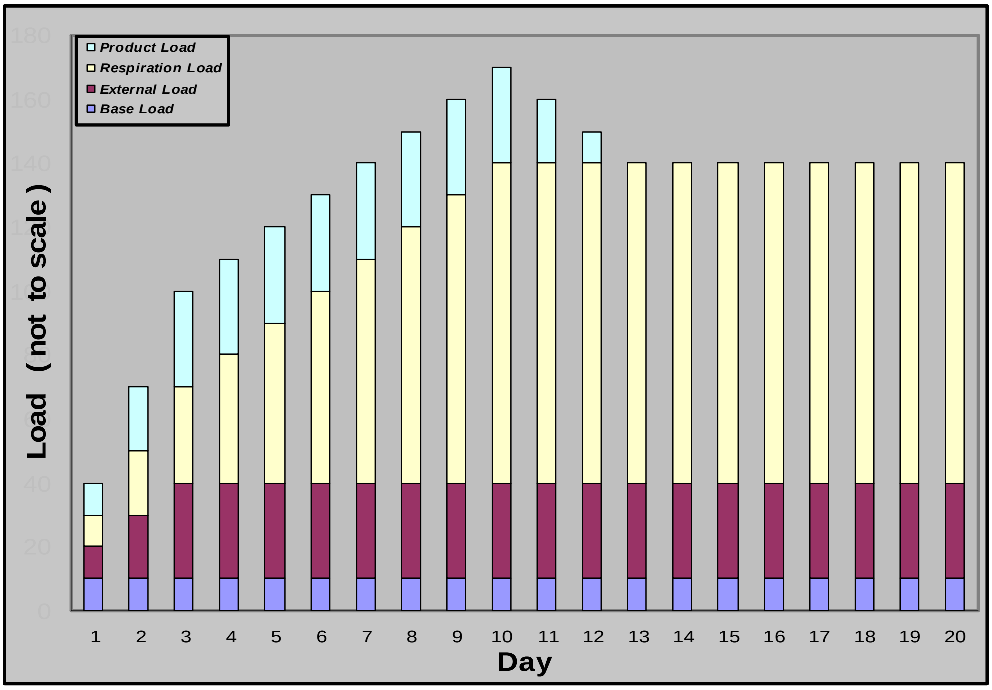

Figure (4) Load distribution case No. 4 (A= 3 , B=10)

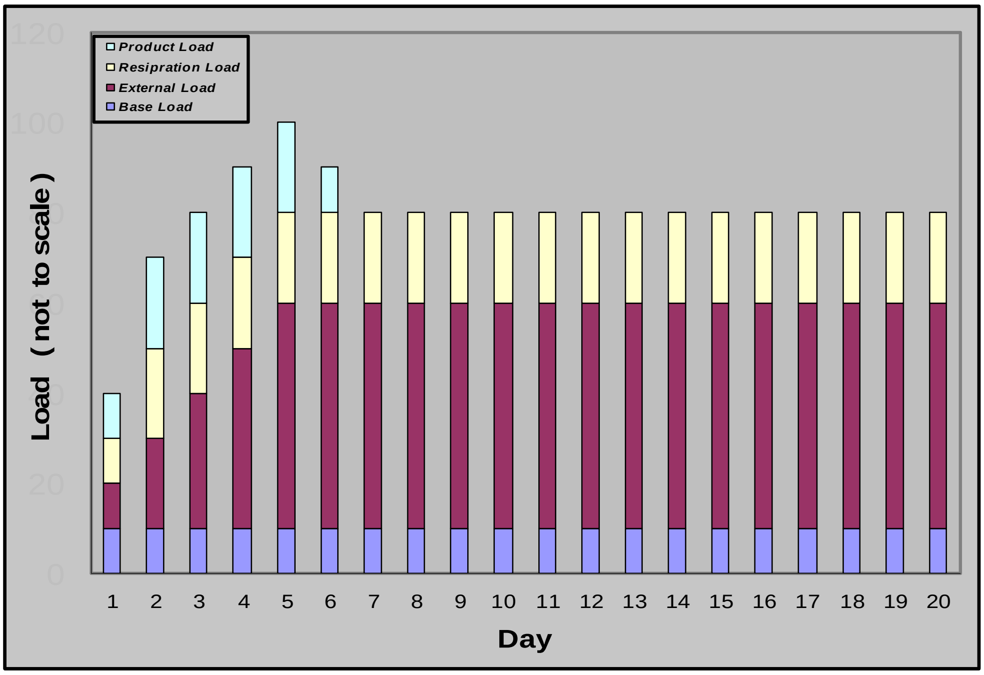

Figure (5) Load distribution case No. 5 (A= 5 , B=2)

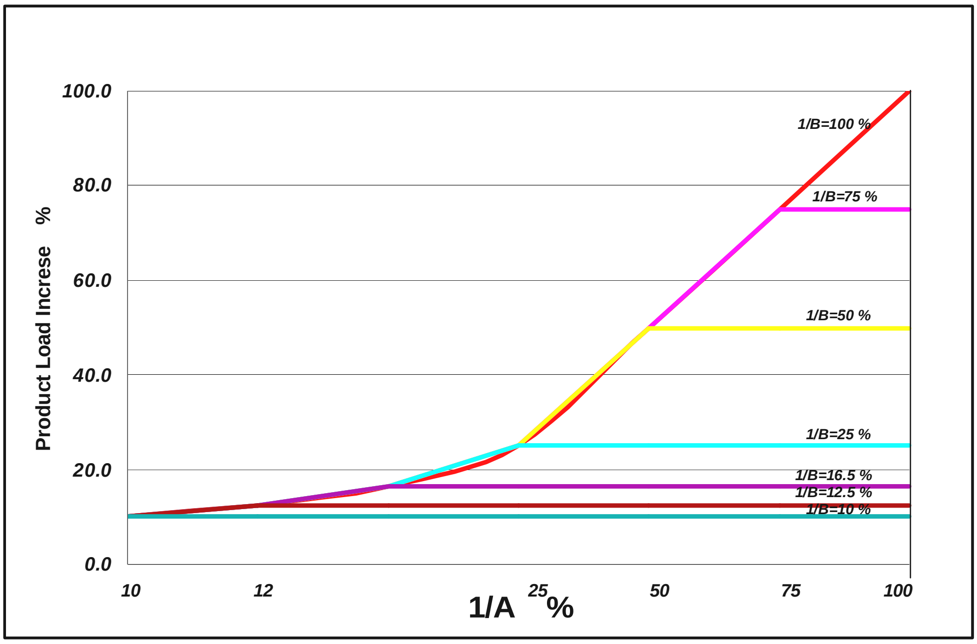

Figure (6) Percentage of product load (Q_6) increasing with respect to 1/A & 1/B