Design And Building Freeze Dryer Chamber

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Abstract

Freeze-drying is a method of removing water by sublimation of ice crystals from frozen material. Suitable parameters of process application allow us to obtain best quality products compared to products dried with traditional methods. In food industry and pharmaceutical field lyophilization has become important subject to ongoing development and its expansion.

Lyophilization that use in the project is not common in Middle East, hence will made prototype objectives to produce products with high quality during freeze-drying process.

الملخص

التجفيف بالتجميد هو عبارة عن طريقة نقوم من خلالها بإزالة المياه عن طريق عملية التسامي للبلورات الثلجية من المادة المفرزة حيث تلعب المتغيرات المناسبة دوراً مهماً في الحصول على أفضل جودة للمنتجات مقارنةً مع (المنتجات) المجففة بالطرق العادية والتقليدية.

إن عملية التجفيف التي يقوم عليها هذا المشروع ليست شائعة في الشرق الأوسط وبالتالي سوف نعمل على تصنيع نموذج يهدف لإنتاج منتجات ذات جودة عالية من خلال عمليات التجفيف بالتجميد.

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1.1 Introduction

Freeze drying is the process of dehydrating frozen foods under a vacuum so the moisture content changes directly from a solid to a gaseous form without having to undergo the intermediate liquid state through sublimation. In this process, freeze dried food maintains its original size and shape with a minimum of cell rupture. Removing moisture prevents a product from deteriorating at room temperature.

This process used for drying and preserving a number of food products, including meats, vegetables, fruits, and instant coffee products.

The dried product will be the same size and shape as the original frozen material and will be found to have excellent stability and convenient reconstitution when placed in water. Freeze dried products will maintain nutrients, color, flavor, and texture often indistinguishable from the original product.

Depending on the product and the packaging environment, freeze dried foods are shelf-stable at room temperature for up to twenty-five years or more, if canned, and between 6 months to 3 years if stored in a poly-bag container, making it perfect for survival food or food storage as well as for commercial use.

1.2 Description

Lyophilization or freeze drying is a process in which water is frozen, followed by its removal from the sample, initially by sublimation (primary drying) and then by desorption (secondary drying). Freeze drying is a process of drying in which water is sublimed from the product after it is frozen[1]. It is a drying process applicable to manufacture of certain foods and pharmaceuticals and biological that are thermo labile for prolonged storage periods.

The term lyophilization describes a process to produce a product that loves the dry state [2]. However, this term does not include the freezing process. Therefore, although lyophilization and freeze-drying are used interchangeably, freeze-drying is a more descriptive term [3]. Freeze drying can used in a number of applications , most commonly in the food and pharmaceutical industries. There are, however, many other uses for the process including the stabilization of living materials such as microbial cultures, preservation of whole animal specimens for museum display, restoration of books and other items damaged by water, and the concentration and recovery of reaction products [4].

The process of freeze-drying has taken on greater prominence in the parenteral industry, due to the advent of recombinant DNA technology. Proteins and peptides must be freeze-dried for clinical and commercial use. There are other technologies available to produce sterile dry powder drug products besides freeze-drying, such as sterile crystallization or spray-drying and powder filling. However, freeze-drying is the most common unit process for manufacturing drug products too unstable to be marketed as solutions [5].

1.3 Applications

1) Pharmaceutical and biotechnology

Pharmaceutical companies often use freeze-drying to increase the shelf life of products, such as vaccines and other injectable.[6] By removing the water from the material and sealing the material in a vial, the material can be easily stored, shipped, and later reconstituted to its original form for injection.

2) Food Industry

Freeze-drying is used to preserve food and make it very lightweight. The process has been popularized in the forms of freeze-dried ice cream, an example of astronaut food.

3) Chemical Industry

In chemical synthesis, products are often freeze dried to make them more stable, or easier to dissolve in water for subsequent use. In bio separations, freeze-drying can be used also as a late-stage purification procedure, because it can effectively remove solvents. Furthermore, it is capable of concentrating substances with low molecular weights that are too small to be removed by a filtration membrane.[7]

1.4 Motivation

Freeze drying is a known process whereby without destroying their inherent physical and chemical characteristics substances, that will offer product with high nutrition value and save proteins and carbohydrates without destroy, that’s mean the product will save same properties approximately after lyophilization and keep it more than 3 year in suitable condition ,and it can use in industrial applications like dried meat and produce medical pharmaceuticals.

1.5 Importance

Freeze-dried foods retain a high percentage of their original nutrients for the most part. This is because the freeze-drying process only removes the water content in food under a low temperature.

1) Reconstitutes to original state when placed in water
2) Shelf stable at room temperature – cold storage not required
3) The weight of the freeze-dried products is reduced by 70 to 90 percent, with no change in volume
4) The product is light weight and easy to handle
5) Shipping costs are reduced because of the light weight and lack of refrigeration
6) Low water activity virtually eliminates microbiological concerns
7) Offers highest quality in a dry product compared to other drying methods as shown in figure(1.1)
8) Virtually any type of food or ingredient, whether solid or liquid, can be freeze-dried

Figure 1 1 dehydrated vs freeze dried

1.6 Objectives

This project aims to build a prototype (freeze dryer) to be available for people, that will be able to produce product freeze dried with high quality from nutrition value ,color and aroma with low cost and without preservation materials and preserve it for long time.in this project **apple** will be used as a product .

Desired characteristics of freeze dried products.

1) Intact cake
2) Sufficient strength
3) Uniform color
4) Sufficiently dry
5) Sufficiently porous
6) Sterile
7) Free of particulates
8) Chemically stable

1.7 Budget

When you going to make any project, you have to take attention that your project will cost a certain amount of money. If you plan to make a development for your project, you must take attention more and more, to minimize the cost as possible as you can, to make a beautiful profit margin. Table 1.1 shows the budget of the system.

Table 1.1 Budget table

Components	**Cost of one unit ($)**
Refrigeration cycle (freezer)	220
Pressure sensor	80
Temperature sensor	30
Thermostat	100
Compressor (as vacuum pump)	100
Base for the freezer	60
Contactors	130
Overloads	70
PLC	200
transformer	20
Switches	30
Electrical board	100
Total	**1145$**

1.8 Time Table of the First Semester

Table (1.2)Time table of first semester

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project selection																
Information gathering																
Determination of task																
Design and analysis																
Documentation																

1.9Time Table of the second Semester

Table (1.3)Time table of second semester

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Collect the parts																
Build prototype																
Documentation																

Chapter 2

State of Art

2.1 Introduction

Drying is an important and traditional process to remove the moisture from the food. The basic principle is that micro organisms such as bacteria, fungi, mold requires water for their growth and multiplication, which causes food spoilage and decay. Since water as a potential medical for pathogens in the food chain and it has to be removed to increase the shelf life of the food products. Drying and dehydration is an ideal process to remove the moisture content applicable to all food materials such as fruits, vegetable, cereals, pulses, milk, meat, fish etc.

2.2 Principles of drying and dehydration by heat

2.2.1 Free and bound water

Water is a basic element in foods which contains positively charged two Hydrogen atoms and one negatively charged Oxygen atom hence water is polar solvent. The bonds between Oxygen and each Hydrogen atom are polar bonds, having 40% partial ionic character. Water is the fundamental component in all living things and almost in all food materials contains more than 75% of water and fruits and vegetables contain water up to 95%. Water that can be easily removed from foods is known as **free water**, whereas water that cannot be removed easily is termed as **bound water**.

Several properties of foods significantly depend on water content. Solute molecules and ions, or chemical groups and surfaces, can be hydrated. There are several relations between water content and some macroscopic property because the part of water is present in the constituents. This water is called bound water. Hydration of water in food components involves small quantities of water. Only polar groups, and to a lesser extent dipoles, can ‘‘bind’’ water molecules.

2.2.2 Benefits of traditional drying

Molds, yeast and bacteria need water to grow. When foods are sufficiently dehydrated, microorganisms cannot grow and foods will not spoil. Dried fruits and fruit leathers may be used as snack foods; dried vegetables may be added to soups, stews or casseroles. Campers and hikers value dried foods for their light weight, keeping qualities and ease of preparation.

2.2.3 Nutritional value

The nutritive value of food is affected by the dehydration process. Vitamins A and C are destroyed by heat and air. Using a sulfite treatment prevents the loss of some vitamins but causes the destruction of thiamin. Blanching vegetables before drying (to destroy enzymes) results in some loss of vitamin C and B-complex vitamins as well as the loss of some minerals, because these are all water soluble. Yet blanching reduces the loss of thiamin and vitamins A and C during dehydration and storage. Dried foods have more calories on a weight-for-weight basis because of their nutrient concentration. For example, 100 grams of fresh apricots has 51 calories, whereas 100 grams of dried apricots has 260 calories. In general, dried foods are not a major part of the American diet, so nutrient loss is not a concern. Nutritive value, as well as flavor and appearance, is best protected by low temperature and low humidity during storage.

2.2.4 Drying methods

Foods can be dehydrated by various means: the sun, a conventional oven, an electric dehydrator or, for herbs only, a microwave oven. Dehydration, like other preservation methods, requires energy. Unless sun drying is possible, the energy cost of dehydrating foods at home is higher than for canning and, in some cases, more expensive than freezing.

2.2.4.1 Solar drying

is a modification of sun drying in which the sun's rays are collected inside a specially designed unit with adequate ventilation for removal of moist air. The temperature in the unit is usually 20 to 30 degrees Fahrenheit higher than in open sunlight, which results in a shorter drying time. While solar drying has many advantages over sun drying, lack of control over the weather is the main problem with both methods.

2.2.4.1 Oven drying

is the most practical way to experiment with dehydration. It requires little initial investment, protects foods from insects and dust and does not depend on the weather. Continual use of an oven for drying is not recommended because ovens are less energy-efficient than dehydrators, and energy costs tend to be high. It is difficult to maintain a low drying temperature in an oven, and foods are more susceptible to scorching at the end of the drying period. Oven-dried foods are usually darker, more brittle and less flavorful than foods dried by a dehydrator.

2.2.4.3 An electric dehydrator

produces a better-quality dried product than any other method of drying. Electric dehydrators are self-contained units with a heat source, a ventilation system, and trays to place the food on. They are used to dry foods indoors. Therefore, as with oven drying, they don't depend on the weather. Such dryers can be purchased or made at home and vary in sophistication and efficiency. Although an electric dehydrator requires a fairly high initial investment, it maintains low temperatures and uses less energy than an oven.

2.2.5 Considerations

It is not recommended that microwave ovens be used for drying foods, because the food will partially cook before it dries, imparting an overcooked flavor. Microwave ovens can be used to dry some herbs quickly—but watch them carefully to prevent them from catching on fire. Check the owner's manual for drying recommendations.

2.2.5.1 Drying times

in conventional ovens or dehydrators vary considerably depending on the amount of food dried, its moisture content and room temperature and humidity—and in the case of oven drying, the use of fans. Some foods require several hours, and others may take more than a day. Interrupting drying time, or prolonging it by using lower temperatures, may result in spoilage.

2.2.5.2Air temperature and circulation

Air temperature must be controlled during the drying process. If the temperature is too low or the humidity too high (resulting in poor circulation of moist air), the food will dry more slowly than it should and microbial growth can occur. Watch temperatures closely at the beginning and end of the drying period. If the temperature is too high at first, a hard shell may develop on the outside, trapping moisture on the inside. This condition is known as case hardening.

Temperatures that are too high at the end of the drying period may cause food to scorch. Temperatures between 120 and 140 degrees F are recommended for drying fruits and vegetables. Temperatures up to 150 degrees F may be used at the beginning, but should be lowered as food begins to dry. For at least the last hour of the drying period, the temperature should not exceed 130 degrees F.

2.3 Principles of drying and dehydration by freeze drying

2.3.1 Principle of freeze drying

The main principle involved in freeze drying is a phenomenon called sublimation, where water passes directly from solid state (ice) to the vapor state without passing through the liquid state.

Sublimation of water can take place at pressures and temperature below triple point (4.579 mm of Hg and 0.0099°C) [7]. The material to be dried is first frozen and then subjected under a high vacuum to heat (by conduction or radiation or by both) so that frozen liquid sublimes leaving only solid ,dried components of the original product.

The concentration gradient of water vapor between the drying front and condenser is the driving force for removal of water during lyophilization [8].figure (2.1) show rate of drying.

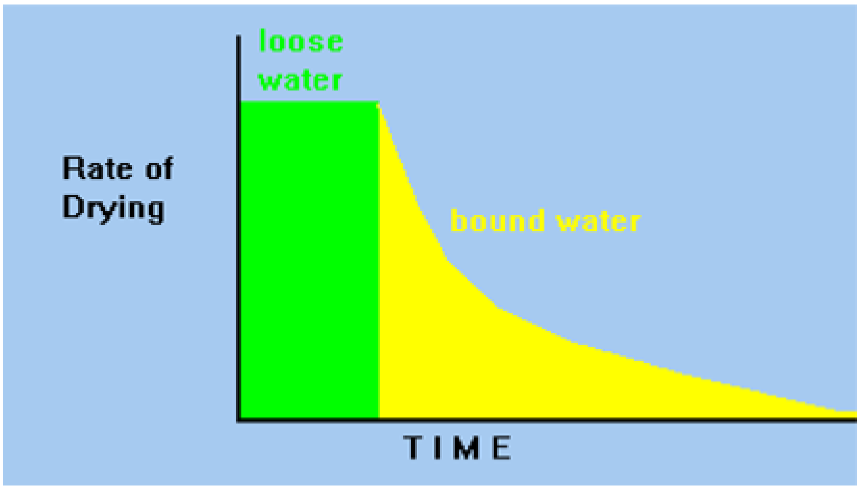

Figure 2 1 Rate of drying water

At atmospheric pressure (approx. 1,000 mbar) water can have three physical states

1) Solid.
2) Liquid.
3) Gaseous.

Below the triple-point (for pure water: 6.1 mbar at 0°C), only the solid and the gaseous states exist (Figure.2.2).

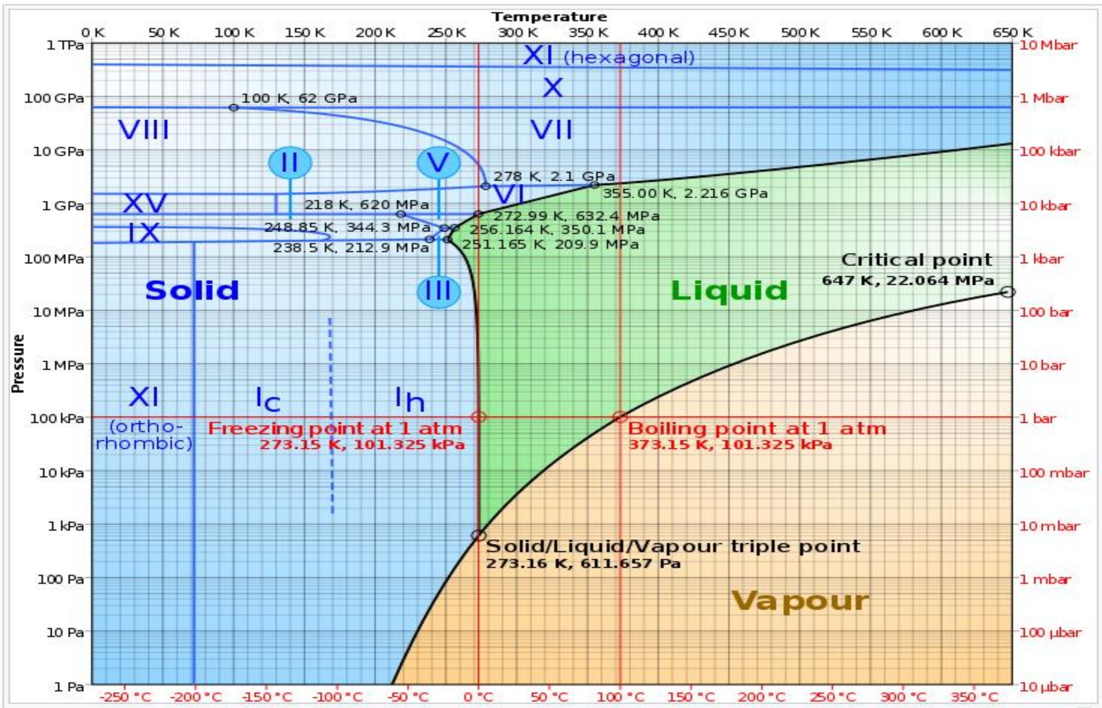

Figure 2 2 phase diagrame of water

The principle of freeze/sublimation-drying is based on this physical fact. The ice in the product is directly converted into water vapor (without passing through the "liquid state") if the ambient partial water vapor pressure is lower than the partial pressure of the ice at its relevant temperature (Table 2.1).

To extract water from product, the process of lyophilization consists of :

1) Freezing the product so that the water in the food become ice.
2) Under a vacuum, sublimating the ice directly into water vapor.
3) Drawing off the water vapor.

Once the ice is sublimated the foods are freeze dried and can be removed from the machine.[10]

Table 2.1 vapor pressure of water

Temperature (°C)	Vacuum (mbar)	Temperature (°C)	Vacuum (mbar)	Temperature (°C)	Vacuum (mbar)	Temperature (°C)	Vacuum (mbar)
0	6.110	-16	1.510	-34	0.250	-54	0.024
-1	5.620	-17	1.370	-35	0.220	-55	0.021
-2	5.170	-18	1.250	-36	0.200	-56	0.018
-3	4.760	-19	1.140	-37	0.180	-57	0.016
-4	4.370	-20	1.030	-38	0.160	-58	0.014
-5	4.020	-21	0.940	-39	0.140	-59	0.012
-6	3.690	-22	0.850	-40	0.120	-60	0.011
-7	3.380	-23	0.770	-41	0.110	-61	0.009
-8	3.010	-24	0.700	-46	0.060	-62	0.008
-9	2.840	-25	0.630	-47	0.055	-63	0.007
-10	2.560	-28	0.470	-48	0.050	-64	0.006
-11	2.380	-29	0.420	-49	0.045	-65	0.0054
-12	2.170	-30	0.370	-50	0.040	-66	0.0047
-13	1.980	-31	0.340	-51	0.035	-67	0.0047
-14	1.810	-32	0.310	-52	0.030	-68	0.0035
-15	1.650	-33	0.280	-53	0.025	-69	0.003

2.4 The stages of freeze-drying process

Freeze drying is mainly used to remove the water from sensitive products, mostly of biological origin, without damaging them, so they can be preserved easily, in a permanently storable state and be reconstituted simply by adding water.[12] Examples of freeze dried products are: antibiotics, bacteria, sera, vaccines, diagnostic medications, protein containing and biotechnological products, cells and tissues, and vegetable and fruits. The product to be dried is frozen under atmospheric pressure. Then, in an initial drying phase referred to as primary drying, the water (in form of ice) is removed by sublimation; in the second phase, called secondary drying, it is removed by desorption. Freeze drying is carried out under vacuum.[11]

2.4.1 Freezing

in which the liquid sample is cooled until pure crystalline ice forms from part of the liquid and the remainder of the sample is freeze-concentrated into a glassy state where the viscosity is too high to allow further crystallization.

2.4.2 Primary drying

A freeze dryer's second phase is primary drying (sublimation), in which the pressure is lowered and heat is added to the material in order for the water to sublimate. The freeze dryer's vacuum speeds sublimation. The freeze dryer's cold condenser provides a surface for the water vapor to adhere and solidify. The condenser also protects the vacuum pump from the water vapor. About 95% of the water in the material is removed in this phase. Primary drying can be a slow process. Too much heat can alter the structure of the material.

2.4.3 Secondary drying

A freeze dryer's final phase is secondary drying (adsorption), during which the ionically-bound water molecules are removed. By raising the temperature higher than in the primary drying phase, the bonds are broken between the material and the water molecules. Freeze dried materials retain a porous structure. After the freeze dryer completes its process, the vacuum can be broken with an inert gas before the material is sealed. Most materials can be dried to 1-5% residual moisture [12].

2.4.4 Dehydration

The dehydration process, is defined as “the application of heat under controlled conditions to remove the majority of the water normally present in a food”. Removal of water can be done by evaporation or sublimation (in case of freeze drying) [13].

The water vapor, removed from the product chamber by a vacuum pump, is directed to a condenser, where it is retained frozen. Figure (2.3) shows the basic configuration of a freeze dryer.

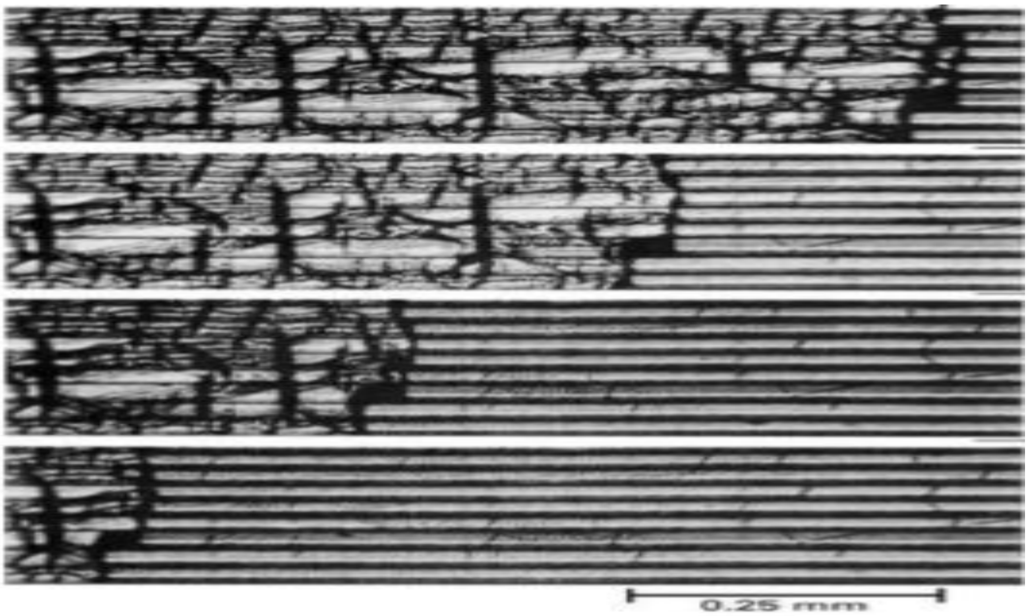

Figure 2 3 sublimation stages

During the freeze drying process, heat is provided to the product in order to sublime the ice and remove the water. Sublimation starts at the surface of the product and then moves toward the bottom. During the process, the dry layer acts as an insulation material and the drying rate slows as the layer thickens [14].

There are a large number of published data showing the superior quality of freeze-dried products [15]. compared the quality characteristics of fresh and freeze-dried alpine strawberries and found no difference between the two products. The researcher evaluated sugar content, pH, color, vitamin C and anthocyanin's, among others, and all the results were very similar between the fresh and dried samples, indicating that the freeze drying process preserved the quality of the fruit.

Evaluated the retention of aroma during air and freeze drying of apples. Three representative compounds of apple flavor were evaluated before, during and after the drying processes. The researchers found a higher retention of flavor in freeze-dried samples, attributed to the lower temperatures used in the process[16].

On the other hand, because of the use of vacuum, sub-zero temperatures, and thermal energy for sublimation and evaporation (phase change), freeze drying is the most expensive drying method. Low temperature drying results in slow drying rates and long drying times. In addition, the low pressure required for sublimation and therefore the use of a vacuum pump, as well as the refrigeration system for maintaining a low temperature to collect moisture in the form of ice on the condenser all add cost to the process. As a result, both the capital investment for purchasing a freeze drying system and the production cost, mainly the high energy consumption, are high compared to other drying technologies. The process is therefore mainly employed for very sensitive foods or high value products [17].

Chapter 3

Calculation

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3.3 Load sources

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3.4.1 Overall heat transfer coefficient U

3.4.2 cooling load calculation:

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3.5.2 Calculation the time of primary drying:-

3.5.3 Calculation the time of secondary drying:-

3.6 calculation of refregarion cycle

3.7 R600a Refrigerant

3.1 Introduction

The cooling load on refrigerating have many source of heat. So this chapter will talk about the load calculation , overall heat transfer and the freeze drying process time. Value of freeze temperature, inside temperature, and freeze drying process time.

3.2 Design the chamber:

1) Chambers temperature is -20 °C
2) Chambers have rectangular shape.
3) Out side dimension of chambers (0.53 *0.53* 0.83) m
4) mass of product is 0.5 kg
5) The insulation is polyurethane with thermal conductivity k=0.036 [$W/m^2.$°C]
6) Thickness of insolation is 0.07m.
7) Specific position for vacuum pumps and wire electrical for sensor and defrost.

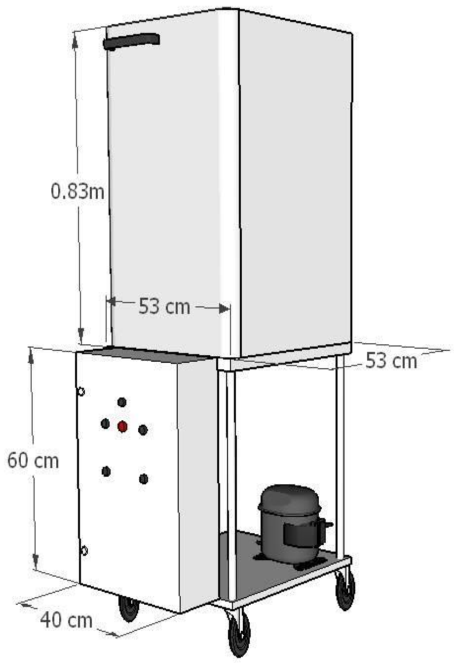


Figure 3 1 The freeze dryer device

3.3 Load sources

1) Load from wall
2) Load from product
3) Load from Packing
4) Load form fan motor

3.4 Calculation:

3.4.1 Overall heat transfer coefficient U:

$$u = \frac{1}{\frac{1}{hi} + \frac{\Delta x}{k} + \frac{1}{ho}}$$

Where:

U: theoverall heat transfer coefficient $[W/m^2.°C]$

Δx: Thickness of layer of wall [m]

K: thermal conductivity of material $[W/m\,.°C]$

h_i: convection heat transfer coefficient of inside air $[W/m^2.°C]$

h_o: convection heat transfer coefficient of outside air $[W/m^2.°C]$

The value of hi when forced convection by using evaporator fan (30-100) is taken 60 as $[W/m^2.°C]$

The value of ho when free convection inside room is taken as 9.3 $[W/m^2.°C]$

Table (3.1) show thickness and thermal conductivity of wall construction

Table3.1: wall construction:

Name of layers	Layer	Thickness mm	k $[W/m^2.°C]$
Sheet of iron	1	0.7	59
polyurethane	2	70	0.036
Sheet of plastic	3	3	0.5

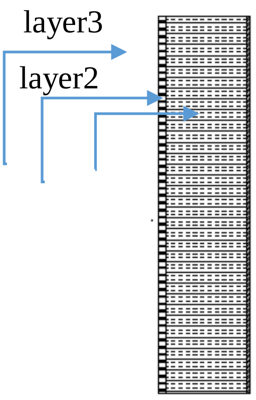


Figure 3 2 wall construction

$$u = \frac{1}{\frac{1}{9.3} + \sum\frac{0.0007}{59} + \frac{0.07}{0.036} + \frac{0.003}{0.5} + \frac{1}{60}}$$

U = 0.507 $[W/m^2.\text{℃}]$

3.4.2 Cooling load calculation:

Q total= Q envelop + Q product + Q packing

3.4.2.1 Q $_{envelop}$:

The heat gain in freezer is due to heat transfer through walls(door, right wall, left wall behind wall , bottom wall, upper wall)

Q wall $_{right}$ = U*A*(T_{out} - T_{in})

Where :

A: outside surface area of the wall [m^2]

U: the overall heat transfer coefficient $[W/m^2.\text{℃}]$

A_{in}: inside area for chamber

A_{out}: outside area for chamber

t_{in} : temperature in side refrigerator = -20℃

t_{out} : temperature un refrigeration space = 35℃

Q From wall

Q wall door:

Q Wall $_{door}$ =U*A*ΔT

Q wall $_{door}$= 0.507*(0.54*0.83) *55

Q wall $_{door}$= 12.49 W

Q From behind

Q $_{behind}$ = Q wall $_{door}$

Q $_{behind}$ = 12.49 W

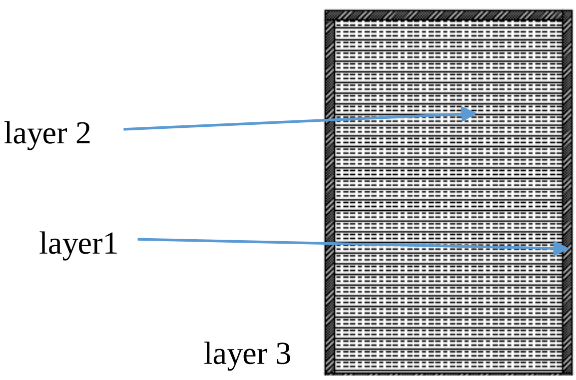


Figure 3 3 wall construction door

Q From left :

Q_{left} =U*A*Δ T

Q_{lift} = 0.507*(0.40*0.83) *55

Q_{left} = 9.25 W

Q From right

Q_{right} = Q_{left}

Q_{right} = 9.25 W

Q from upper wall :

Q_{upper} =U*A*Δ T

Q_{upper} = 0.507*(0.40*0.40) *55

Q_{upper} = 4.46 W

From bottom

Q_{bottom} = Q_{top}

Q_{bottom} = 4.46 W

Q envelop total = 52.5 W

3.4.2.2 Q product :

The heat gain from product

$Q_p = Q_1 + Q_2$

When ;

Q_1 : Heat required to cool the product from initial temperatures to desire temperatures.

Q_2 : The latent heat freezing.

Cp: Specific heat for apple

t_{in} : Temperature of apple cooling = 3℃

Time $_{cooling}$: The time required to have sit point (exp) = 3600 [s]

$Q_1 = \frac{mass\ \text{apple}}{time\ cooling} * cp_{\ apple} * (T_{\ out} - T_{\ in})$

$Q_1 = \frac{0.5}{3600} * 3.64 * (35 - 3)$

$Q_1 = 0.017$ W

$Q_2 = \frac{mass\ \text{apple}}{time\ freezing} * q$ fusion "latent "

Where

$q_{\ fusion}$:The fusion energy gain factor

Time $_{freezing}$: The time required to have set point (exp) = 7200 [s]

$Q_2 = \frac{0.5}{7200} * 0.334$

$Q_2 = 2.3*10^{-3}$ W

$Q_{\ p} = 0.0193$ W

3.4.2.3 Q packing

The heat gain from packing

$Q_{\ packing} = \frac{mass\ alaminum}{time\ cooling} * cp_{\ AL} * (T_{out} - T_{\ in})$

$Q_{\ packing} = \frac{1}{3600} * 0.22 * (35 - -20)$

$Q_{\ packing} = 3.36*10\text{-}^{3}$ W

Q packing = 0.0336 W

Q $_{fan}$ motor

The heat gain from fan motor

Q = 25 W

Total q = $Q_{\ products} + Q_{\ envelop} + Q_{\ packing} + Q_{\ motor}$

Q total = 77. 26 W

Add 30% Q_T as a factor of safety

Q_T= Q total *1.3

Q_T = 72.26 *1.3

Q_T = 100.43 W

3.5 Calculation of freeze drying stages :-

3.5.1 Calculation the time of freezing (te):-

We choose the apple to determine approximate time we want for process:-

The freezing time (te) is approximately given by below equation [18]:

$$te = \frac{\Delta h}{\Delta T \rho (\frac{d^2}{2\lambda} + \frac{d}{Ksu})}$$

Where:-

te = freezing time;

Δh = enthalpy difference between the initial freezing point and the final temperature;

ΔT = difference of temperature between the freezing point and the cooling medium;

d = thickness of the product parallel to direction of prevailing heat transfer;

ρ = density of the frozen product;

λ = thermal conductivity of the frozen product;

K_{su} = surface heat transfer coefficient between cooling medium and the freezing zone.

$\Delta h = h@0°\text{C} - h@-20°\text{c}$

$\Delta h = 3.69 kJ/kg - 1.95 kJ/kg = 1.74 kJ/kg$

$\Delta T = -20 - (-25) = 5°\text{c}$

$d = 0.01m$

$\rho = 845\ kg/m^3$

$\lambda = 0.427\ w/m°\text{c}$

K_{su} = $496.8\ kJ/m^2\ h°\text{c}$

Then:-

$\boldsymbol{te = 2\ hour}$

3.5.2 Calculation the time of primary drying (tmd):-

The time of the main drying "primary drying" (approximately) part of the freeze-drying cycle given by equation below [18]:-

$$tmd = \frac{\rho \xi LS \Delta md}{Ttot[\left(\frac{1}{Ktot}\right) + \left(\frac{d}{2\lambda}\right) + (\frac{d}{2LS\ b/\mu})\ ]}$$

where :-

ρ = density of the frozen product (kg/m^3);

ξ = part of water (kg/kg);

LS = sublimation energy (2.805kJ/kg);

$Ttot$ = temperature difference (Tsh-Tice);

$Ktot$ = total heat transmission coefficient from the shelf to the sublimation front of the ice;

λ = thermal conductivity of the frozen product;

d = thickness of the layer (m);

Δm = content of frozen water=0.9

b/μ = permeability (kg/m h mbar) for water vapor through the dried product.

$\rho = 845\ kg/m^3$

$\xi = 0.504$ kg/kg[18]

LS=2.805 kJ/kg[18]

$Ttot = 1.5 - (-20) = 21.5°\mathrm{C}$

$Ktot = 144.9\ \mathrm{kg/m^2\ h\ °C}$

$\lambda = 0.427\ w/m°\mathrm{C}$

$d = 0.01m$

$\Delta m = 0.9$

$b/\mu =\ 0.013\ \mathrm{kg/m\ h\ mbar}$

$$tmd = \frac{10.75}{21.5 * [(0.0069) + (0.012) + 0.137]}$$

$\boldsymbol{tmd = 4\ hour}$

3.5.3 Calculation the time of secondary drying (SD):-

To calculate the secondary drying time (SD) (approximately) we want to determine the desorption of water vapor in per cent of solids per hour (DR) that calculated by below equation[18].

$DR = 289(V_{ch}/m_{so})(dp/dt)$

Where

DR = desorption of water vapor in per cent of solids per hour;

V_{ch} = chamber volume (L)

dp = pressure rise (mbar)

dt = time of dp (s)

m_{so} = mass of solids (g)

$V_{ch} = \frac{\pi}{4} * \ D^2 * L$

Where:

D: diameter of the chamber(m)

L: length of the chamber(m)

$V_{ch} = \frac{\pi}{4} * \ 0.1^2 * 0.155*1000$

$V_{ch} = 1.2L$

$dp@ - 20°C = 0.032$ mbar from table 2.1

$dt = 5\ sec$

$m_{so} = 1000g$

$DR = 289\left(\frac{1.2}{1000}\right) * (\frac{0.032}{2})$

$DR = 3.5\%/h$

The most last study's say the residual water in apple after mean drying is 3%_10%

We suppose in the project the residual water is 10%

Then the time of secondary drying is:-

$$SD = \left(\frac{10\%}{DR}\right) = \left(\frac{10\%}{\frac{3.5\%}{h}}\right) = 2.8 hour$$

$\boldsymbol{SD = 2.8\ hr}$

The total time of processes **=** time of freezing + time of primary drying + time of secondary drying

The total time = 2+4+2.8 **= 8.8hours**

3.6 calculation of refrigeration cycle :

This calculations by cool back:

Refrigerant:

R600a Data:

Te [°C]	=	-20.00
Tc [°C]	=	40.00

Calculated [kJ/kg]:

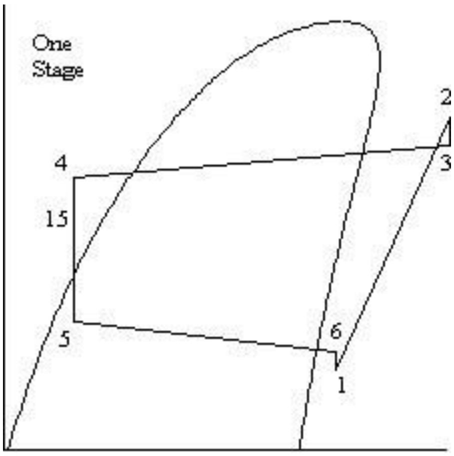
Qe [kJ/kg]	=	241.099
Qc [kJ/kg]	=	317.159
W [kJ/kg]	=	76.060
COP [-]	=	3.17
Pressure ratio [-]	=	7.364

Calculated [kW] :

Qe [kW]	=	0.100
Qc [kW]	=	0.132
m [kg/s]	=	0.000414 77
V [m^3/h]	=	0.7354
Volumetric efficiency	=	0.00
Displacement [m^3/h]	=	0
W [kW]	=	0.032
Q loss [kW]	=	0.000

Refrigerant: R600a

Values at points 1-6,15 for the selected one stage cycle



Point T P v h s

	[°C]	[bar]	[m^3/kg]	[kJ/kg]	[kJ/(kg K)]
1	-15.000	0.728	0.492477	536.281	2.3353
2	41.323	5.359	0.073388	612.342	2.3353
3	41.323	5.359	0.073388	612.342	2.3353
4	40.000	5.359	N/A	295.182	N/A
5	-20.000	0.728	N/A	295.182	N/A
6	-15.000	0.728	0.492474	536.281	2.3353
15	N/A	5.359	N/A	295.182	N/A

3.7 R600a Refrigerant

R600a is the common name for high purity isobutane (C_4H_{10}) suitable for use in the refrigeration and air conditioning industry.

Advantages of R600a

- Zero ozone depletion potential
- Very low global warming potential (~4)*
- Excellent thermodynamic properties leading to high energy efficiency
- Good compatibility with components
- Low charges allowing smaller heat exchangers and piping dimensions

Common applications R600a

has a number of applications. It is most suited to high and medium temperature applications. The most common applications are for use in domestic refrigeration (refrigerators and freezers), with over 250 million units using the product. Other applications include small display cabinets and vending machines.

Electrical design

Chapter 4

4.1 Introduction

This chapter will talk about electrical circuits and control methods during this project , as talk in previous chapter about what parameters want to control in the main components of the system .

4.2 Controller :

To monitoring the process , display of the value of sensor, alarms management and actuators control.

4.2.1 Programmable Logic Controller (PLC)

The PLC FATEK,FBs-24MAR2-AC show fig 4 1. receives information from connected sensors or input devices, processes the data, and triggers outputs based on pre-programmed parameters.
Depending on the inputs and outputs, a PLC can monitor and record run-time data such as machine productivity or operating temperature, automatically start and stop processes, generate alarms if a machine malfunctions, and more. Programmable Logic Controllers are a flexible and robust control solution, adaptable to almost any application.

Figure 4 1 plc fatek

4.2.2. Temperature controller:

Is an instrument used to control temperatures, mainly without extensive operator involvement. A controller in a temperature control system will accept a temperature sensor such as a thermocouple or RTD as input and compare the actual temperature to the desired control temperature, or set point. It will then provide an output to a control element.

In this project used temperature to convert digital signal to analog signal then take to plc show fig 4 2 .

Figure 4 2 *Temperature controller*

4.3 flow chart for the process

A flowchart is a type of diagram that represents an algorithm, workflow or process. The flowchart shows the steps as boxes of various kinds, and their order by connecting the boxes with arrows. Flowcharts are used in analyzing, designing, documenting or managing a process or program in various fields show fig 4 3, fig 4 4.

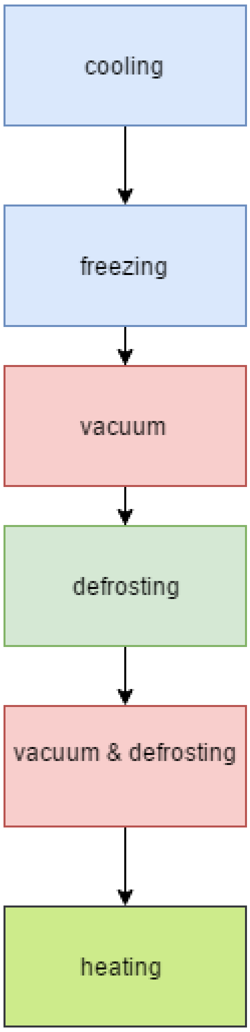


Figure 4 3 flow chart for the contrl system

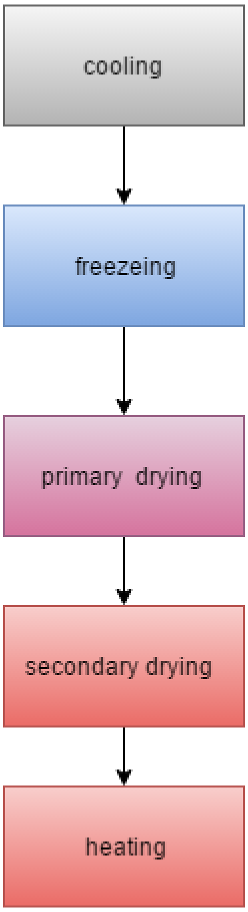


Figure 4 4 flow chart for the process

4.4 Control of cycle using PLC

There are two mods used in the project to control is automatic mode and manual mode:

1) **Manual mode**

In manual mode every parts work alone from switches on electrical panel

2) **Automatic mode**

When select the automatic mode by select switch on electrical panel

The device will work as plc program

PLC program

1) The compressor and evaporator fan will work together immediately when select automatic mode
2) Temperature sensor measure the temperature to stay at 1°C.
3) Then refrigeration cycle working for 1 hour to decrease temperature of chamber to -20 ℃.
4) When temperature reach to -20 ℃ the refrigeration cycle off and vacuum pump work for 5 hour to save constant pressure (5 mbar) .
5) Start defrosting until temperature exceed to 1°C
6) Then starting heating to "27℃" and vacuum"2 mbar" this process up to 3 hour.
7) After end this processes the system off and selector open .

4.5 Programming

This is most important step in the project, to make PLC work we must build a program and download it to the PLC , the designer need to transfer what he thinks to the program to make any controller work right, and this is what we do, where we used Fatek PLC we must use Fatek software "win proladder" to build our program show fig 4 4 , fig 4 6.

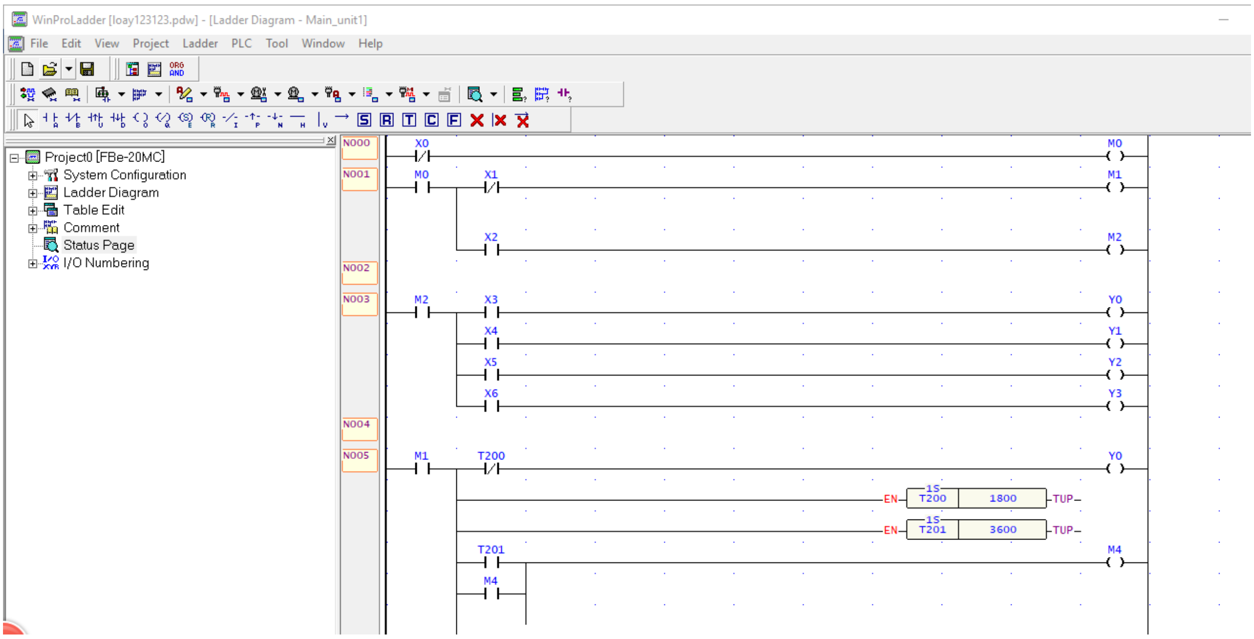


Figure 4 5 *plc control 1 by software*

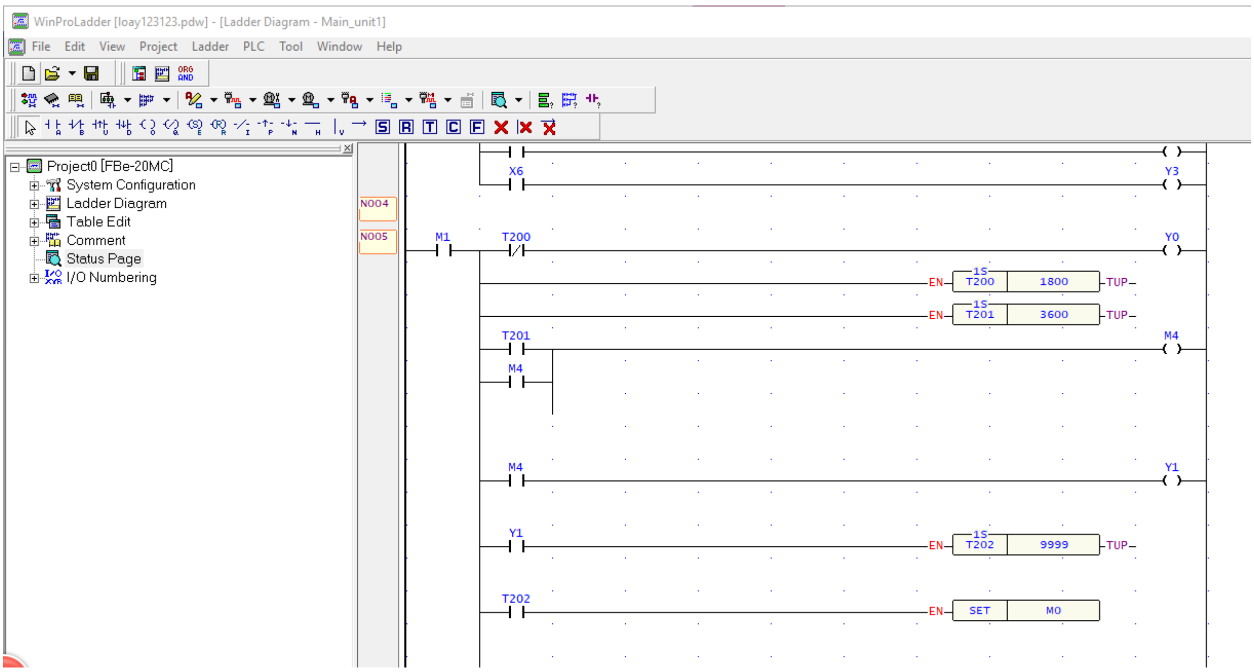


Figure 4 6 *plc control 2 software*

4.6 Power circuit:

The circuit I phase 220 v have 4 contactors and 2 over load show fig 4 7.

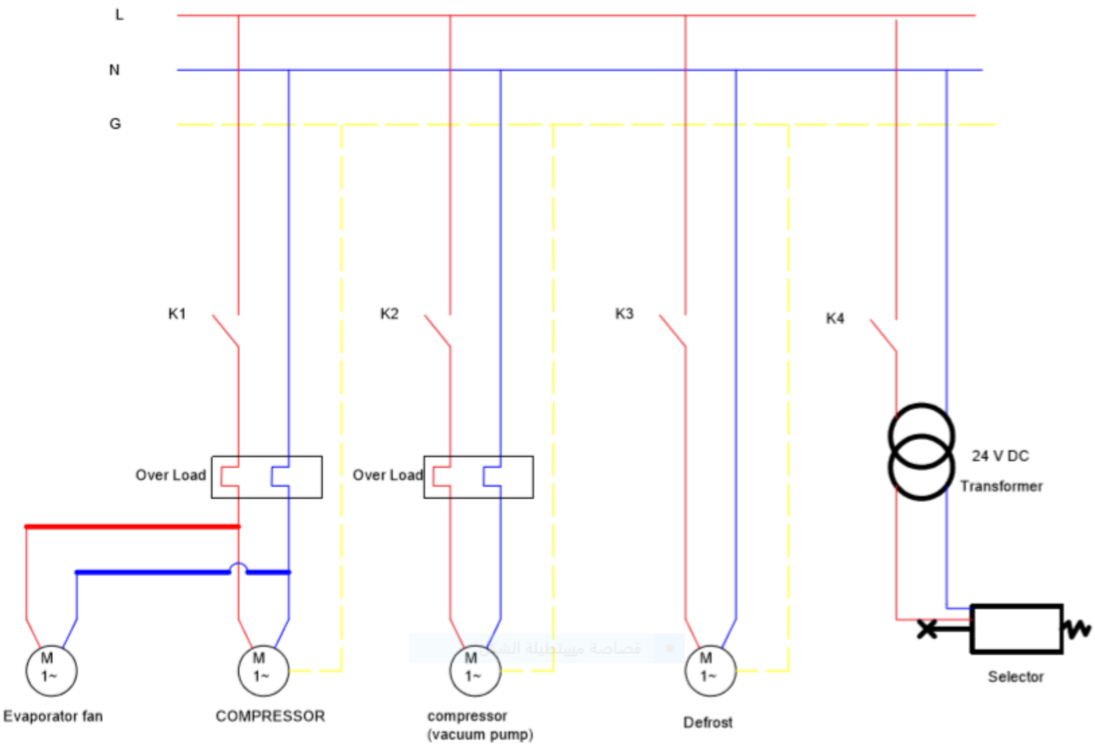


Figure 4 7 power circuit

4.7 Sensors:

Sensors are used to send actual values of the parameters in the process to PLC memory, in this project we used group of sensors with varies types, characteristics and functions .At follow we show these sensors and its positions in the system .

4.7.1 Temperature sensor (thermo couple):

We show that the most important parameter in system is temperature . and we must keep temperature in the system and condition process at set value so to do that we used temperature sensor for control show fig 4 8.

Figure 4 8 thermo couple

4.7.2 Pressure sensor

A pressure sensor is a device that detects a force exerted on a surface (pressure) and converts it to an electronic signal whose strength is relative to the strength of the force. Pressure sensors can also be used to measure the force exerted show fig 4 9.

Figure 4 9 Pressure sensor

4.8 Electrical component :

4.8.1:Contactors

A contactor is an electrically-controlled switch used for switching an electrical power circuit. A contactor is typically controlled by a circuit, which has a much lower power level than the switched circuit, such as a 24-volt coil electromagnet controlling a 230-volt motor switch show fig 4 10.

Figure 4 10 contactor

4.8.2 Overloads

An electric overload occurs when **too much current** passes through electric wires. The wires heat and can melt, with the risk of starting a **fire** show fig 4 11.

Figure 4 11 over load

4.9 Switches

The prototype have tow types of switches

4.9.1 Emergency switch

Figure 3.12 shows the emergency switch. An Emergency switch is defined as a fail-safe control switch or circuit that, when de-energized, will stop the operation of associated equipment and will shut off all potential hazards outside the main power enclosure. Emergency switch, or "EStops", are a special type of pilot device that perform the emergency shutdown operation on a machine or electrical system. In this project

Figure 4 12 Emergency switc

4.9.2 Selector switch

Figure 3.13 shows the switch that have been used in the system. Switch is an electrical component that can "make" or "break" an electrical circuit, interrupting the current or diverting it from one conductor to another, in the system there is two switches, one for reset and the other is for turn on the system or turn it off

Figure 4 123 Selector switc

Chapter 5

Prototype design

5.1 Introduction

After design the refrigeration system theoretically and identify requested that is needed for the process, the parts of refrigeration system are assembled with accessories to build the prototype show fig 5 1.

5.2 prototype components

The prototype have many components consist from:-

1) Refrigeration cycle
2) Vacuum system
3) Defrosting
4) Air selector

Figure 5 1 freeze drying devive

5.2.1 Refrigeration cycle components

In this project, the simple refrigeration cycle is used to freeze the product until -20 C for (fist process).

Refrigeration cycle is the vapor-compression refrigeration cycle, where the refrigerant is vaporized and condenses alternately and is compressed in the vapor phase.

Refrigeration cycle used to transfer heat from a lower temperature region to a higher temperature region. Transfer heat from inside chamber from product then reject heat to outside chamber this process need work which electrical compressors supply figure 5.2 explain.

All calculation and energy for this cycle include in chapter 3 (calculated by software).

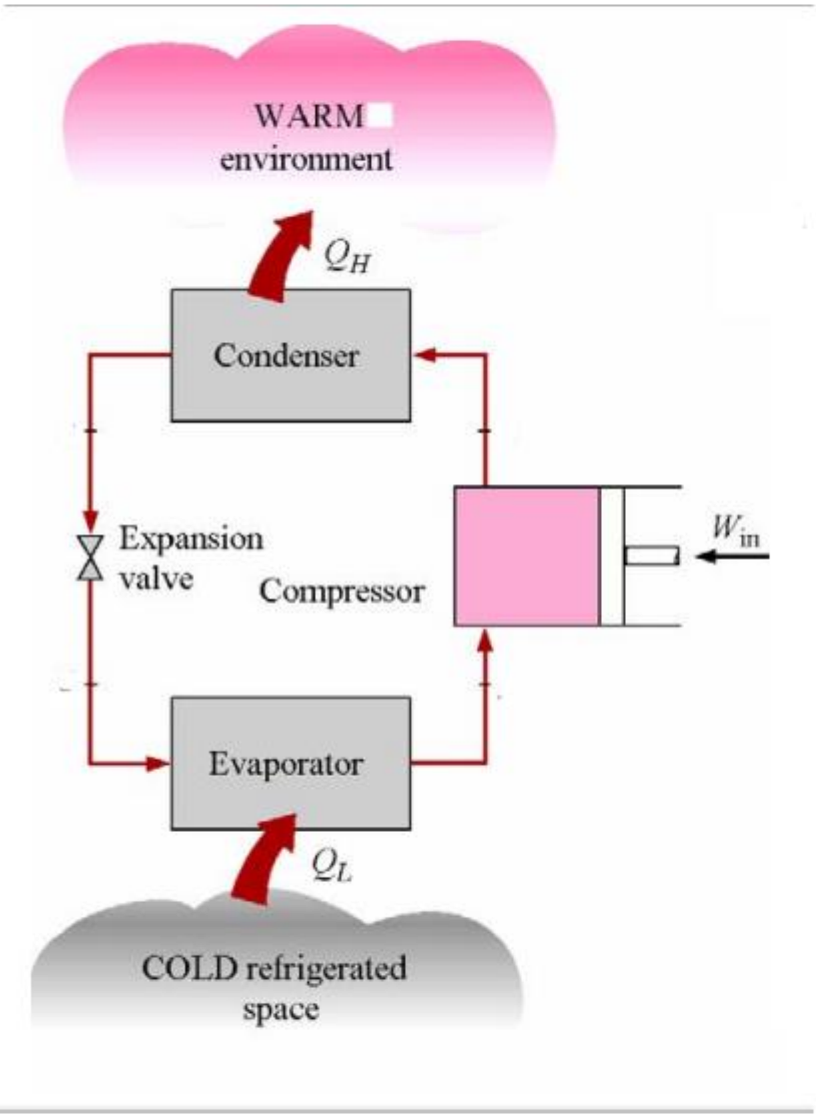


Figure 5 2 explain basic refrigeration cycle

Energy analysis for the chamber to explain when energy out and energy in see fig 5.3.

Q_L: the energy need to freeze product.

Q_H: the energy rejection from the cycle

W_{in}: work for cycle (compressor)

The basic refrigeration cycle have main four components as shown in figure 5.3 .

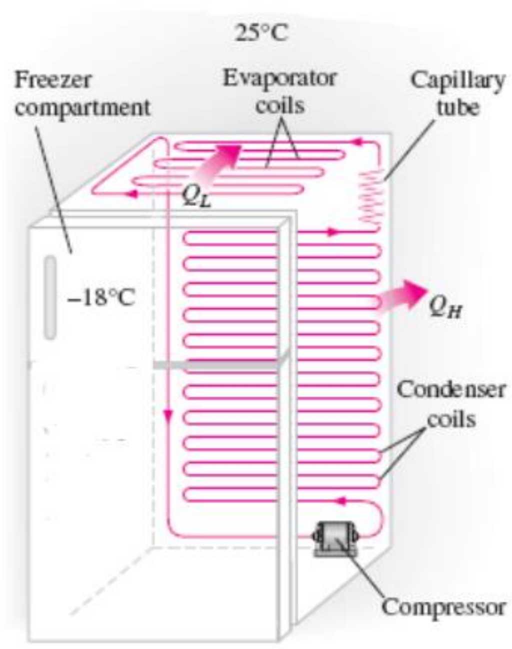


Figure 5 3 Energy analysis

5.2.1.1 Compressor

Using a small hermetic compressor model. For a hermetic unit of fixed design, the performance is governed by the following parameters figure 5.4.

1. Refrigerant type
2. Inlet temperature

3. Inlet pressure

4. Outlet pressure

5. Line voltage

6. Line frequency

Figure 5 4 compressor

5.2.1.2Condenser

The condenser rejects heat from the refrigeration system that the evaporator absorbed and the compressor pumped. The condenser receives the hot gas after it leaves the compressor through the discharge line and is forced into the top of the condenser coil by the compressor figure 5.5 show the condenser that used in project.

The type of condenser air-cooled heat exchanger (free convection) of fixed design, the performance is governed by

l. Refrigerant flow rate

2. Refrigerant inlet state

3. Air flow rate

4. Air inlet state

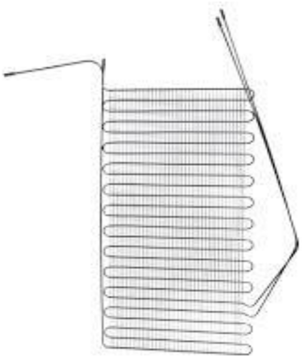


Figure 5 5 condenser

5.2.1.3Evaporator

The evaporator absorbs heat into the system. When the refrigerant is boiled at a lower temperature than that of the substance to be cooled figure 5.6.

The type of evaporator is air heat exchanger of fixed design the same heat exchanger, the performance is governed by

1. Refrigerant flow rate
2. Refrigerant inlet state
3. Air flow rate
4. Air inlet state

.

Figure 5.6 evaporator

5.2.1.4Throttling device "Capillary tube"

The capillary tube is a metering device which holds back the full flow of refrigerant and is the dividing point between the high pressure and low pressure sides of the system. Can choice the diameter for capillary tube by the capacity of compressor, the diameter that used in the project is 0.5mm figure 5.7.

Figure 5 7 capillary tube

5.2.1.5Auxiliary components of refrigeration cycle

Filter dryer

It filters the dirt and iron particles from the refrigerant. Some filter Dryer have moisture absorbent materials like, Silica gel or synthetic silicates, which removes moisture from the refrigerant. The filter/dryer protects the compressor by restricting and filtering the impurities and moisture contents in the refrigerant figure 5.8.

Figure 5 8-filter dryer

5.2.2 Vacuum system

5.2.2.1 Vacuum pump

In the project, we use reciprocating compressor as vacuum pump to reduce the pressure in the chamber figure 5.9.

The specifications of the vacuum pu.mp is

1. Phase number 1 PH
2. Voltage/Frequency (V/Hz) 220V 50Hz
3. Displacement (cm3) 6.65
4. Diameter (mm) 22.0
5. Stroke (mm) 17.47

Figure 5 9 vacuum pump

5.2.2.2 Vacuum chamber:

The vacuum chamber using to contain the product. Chamber made from Aluminium because its have high thermal conductivity and the chamber takes cylindrical shape volume 11.77 cm^2 as figure 5.10.

In ports of chamber:

1. Vacuum pipe
2. Pressure sensor pipe
3. Temperature sensor
4. Selector pipe.

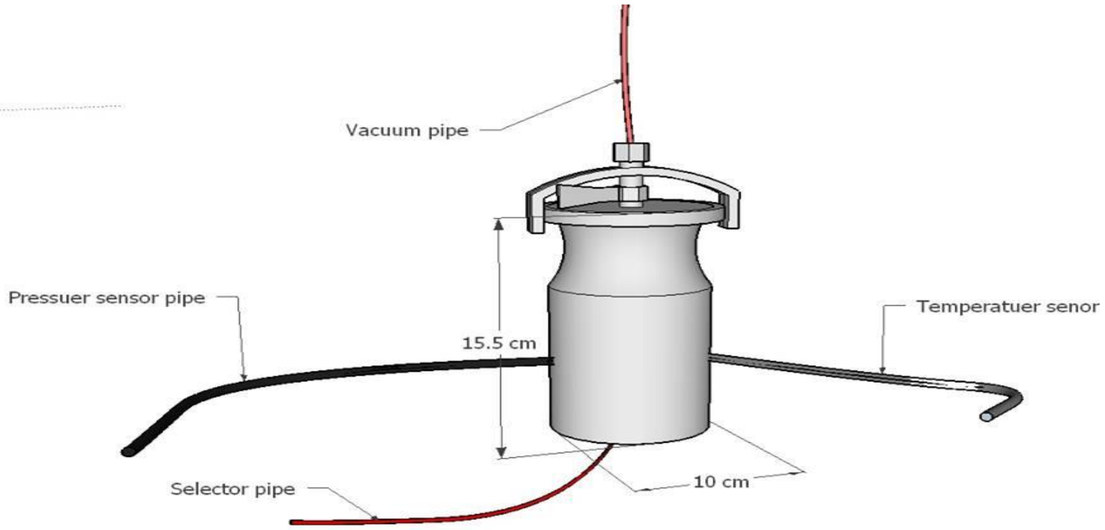


Figure 5 10 vacuum chamber

5.2.3 Heater

The heater used in secondary drying to remove the bound water from the product figure 5.11.

Heater specifications is.

1. Watt rating 725 W,
2. Single tube,
3. High heat capability
(Compatible exact
replacement part)

Figure 5 11 Heater

5.2.4 Air selector:

Used to control in pressure by multiple inlets and outlets. In the project used increase the pressure in the chamber when take the commands from PLC figuer5.12.

Figure 5 12 Air selector

Chapter 6

Results & recommendations

6.1 Introduction

6.2 Results after build the prototype

6.3 Recommendation

6.1 Introduction:-

After build the prototype, several experiments tried on apple fruit. to have the best form as possible and the best performance of the device. In addition, will show results and recommendation in this chapter.

6.2 Results after build the prototype

Several experiments conducted on an apple sample and some fruits and appeared the following results.

1) The mass of product reduced to 83% with change in colour.
2) The product after dehydration was brittle
3) The pressure reach to 10-kpa figuer6.1.

Figure 6 1 vacuume sensor

4) The temperature reach to-21°C figure 6.2.

Figure 6 2 thermostat

5) The loading time 45 minute.
6) The freezing time 30 minute.
7) Time of primary drying 5 hour. If this time increased, the percent of dried water from the product will increase.
8) Time of secondary drying 3 hour. To have product with better quality the time of secondary drying must increase.

9) Total time theoretically of this process is 10 hour, and by experimental Approximately 9, hours are enough to produce the product with good specifications, but if we want to increase the quality, we need to increase this time.

10) The shape of product before and after drying show as figure 6.3 & 6.4 .

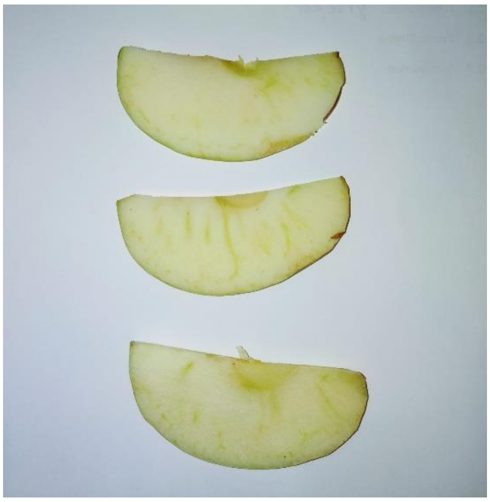


Figure 6 3 product befor freezeing

Figure 6 4 product after freeze drying processe

6.3 Recommendation

1) The chamber tray should be made from material that does not effect on foods quality such as Aluminum

2) The wall of the chamber must be high thermal conductivity because it maintains the quality of the product and speeds up the process

3) Evaporator should be wrapped around the chamber. This method is better than placing the evaporator at one side

4) Use methods to speed up the freeze so it maintains product quality such as fan

5) Product thickness should not exceed to 1.5cm

References:-

1)Akers MJ, Fites AL, Robinson RL. Types of parenteral administration. Journal of parenteral science and Technology, 1987; 41: 88-95.

2) Lippincolt, Williams K. Remington, The Science & practice of pharmacy, Parenteral Preparation, 20th ed, ISE publication, Phelabelphia. 2000; 1: 804 819.

3) Akers MJ, Remington: The science and practice of pharmacy, Lippincott Williams & wilkins publisher, 2000; 21: 525.

4) Flink JM. and Knudsen, An Introduction to Freeze Drying. Strandberg Bogtryk Offset, Denmark. 1983.

5) Nail SL. et al. Fundamentals of freeze-drying. Development and Manufacture of Protein Pharmaceuticals.Marcel Dekker, 2002; 281–360.

6) Chien & Yiew W. Pharmaceutical Dosage forms: Parenteral Medications. Indian Journal of pharmaceutical science and technology, 1981; 35: 106-118.

7) Liberman HA, Lachman L and Schwartz BJ. Pharmaceutical dosage form: Parenterals, Marcel Dekker publisher, 1989;

8) Neema S, Washkuhn RJ and Brendel RJ. Injectable products. PDA J Pharm SciTechnol, 1997; 51: 166-171.

9) Sanjith NL & Gatin LA. Freeze drying: Annealing principles and practice. NP publication. 1993; 2: 163-233.

10) Gatin LA, Auffret T, Shalaev EY, Speaker SM and Teagarden DL. Freeze Drying Concepts: The Basics in Formulation and delivery, Informa Healthcare, New York, 2008; 15: 177-195.

11) Craig DM, Royall PG, Kett VL and Hopton ML. The relevance of the amorphous state to pharmaceutical dosage forms: glassy drugs and freeze dried systems. International journal of pharmaceutical sciences, 1999; 179 207.

12) Yoshioka S, Aso Y and Kojima S. The effect of excipients on the molecular mobility of lyopihilized formulations, as measured by glass transition temperature and NMR relaxationbased critical mobility temperature. Pharm Res, 1999; 135-140

13) Sugimoto I, Ishihara T, Habata H and Nakagawa H. Stability of lyophilized sodium prasterone sulfate. J Parenter Sci Technol, 1981; 35: 88-92.

14) Fellows, P.J. 2000. Food Processing Technology. 2nd ed. Boca Raton: CRC Press, p. 311-340.

15) Zhang, M., Tang, J., Mujumdar, A.S. and Wang, S. 2006. Trends in microwave-related drying of fruits and vegetables. Trends Food Sci. Technol. 17, 524-534.

16)Yurdugül, S. 2008. An evaluation of the retention of quality characteristics in fresh and freezedried alpine strawberries. Int. J. Food Sci. Technol. 43, 865870.

17)Krokida, M.K. and Philippopoulos, C. 2006. Volatility of apples during air and freeze drying. J. Food Eng. 73, 135-141.

18) Steinbach, G. (1994) Die Bedeutung des Einfriervorganges, Berechnung des Gefriervorganges, Verein Deutscher Ingenieure, VDI-Bildungswerk, RW 1570, p. 3.

Other references

1)Wikipedia https://www.wikipedia.org/
2) Cool back https://www.et.du.dk/CoolPack

APPENDIX A

Table A-1 specific heat of capacities

Substance	J/kg/°C or J/kg/K	cal/g/°C or cal/g/K
Water (0 °C to 100 °C)	4186	1.000
Methyl Alcohol	2549	0.609
Ice (-10 °C to 0 °C)	2093	0.500
Steam (100 °C)	2009	0.480
Benzene	1750	0.418
Wood (typical)	1674	0.400
Soil (typical)	1046	0.250
Air (50 °C)	1046	0.250
Aluminum	900	0.215
Marble	858	0.205
Glass (typical)	837	0.200
Iron/Steel	452	0.108
Copper	387	0.0924
Silver	236	0.0564
Mercury	138	0.0330
Gold	130	0.0310
Lead	128	0.0305

Table A-2 Recommended Refrigerant Velocities

Line	Refrigerant		Recommended Velocity (m/s)
Suction	R12	R22	**8-12**
	R-134a		**10-20**
Discharge	R12	R22	**10-18**
	R-134a		**12-25**
Liquid Between Condenser and Refrigerant	R12	R22	**1-1.25**
	R-134a		**0.5-0.7**
Discharge and suction with pump in system	R12	R22	**0.3-0.5**
	R-134a		**0.6-1.2**

Table A-3 Dimensions and physical Characteristics of Copper Tube ACR (Air – Conditioning and Refrigeration Fields Service).

Nominal or Standard Size, inches	Nominal Dimensions, inches			Calculated Values (based on nominal dimensions)				
	Outside Diameter	Inside Diameter	Wall Thickness	Cross Sectional Area of Bore, sq.inches	Weight of Tube Only, pounds per linear ft.	Weight of Tube & Water, pounds per linear ft.	Contents of Tube per linear ft.	
							Cu ft.	Gal
1/4	0.375	0.315	0.030	0.078	0.126	0.160	0.00054	0.00405
3/8	0.500	0.430	0.035	0.145	0.198	0.261	0.00101	0.007575
1/2	0.625	0.545	0.040	0.233	0.285	0.386	0.00162	0.01215
5/8	0.750	0.666	0.042	0.348	0.362	0.512	0.00242	0.01815
3/4	0.875	0.785	0.045	0.484	0.455	0.664	0.00336	0.0252
1	1.125	1.025	0.050	0.825	0.655	1.010	0.00573	0.042975
1 1/4	1.375	1.265	0.055	1.260	0.884	1.430	0.00875	0.065625
1 1/2	1.625	1.505	0.060	1.780	1.140	1.910	0.0124	0.093
2	2.125	1.985	0.070	3.090	1.750	3.090	0.0215	0.16125
2 1/2	2.625	2.465	0.080	4.770	2.480	4.540	0.0331	0.24825
3	3.125	2.945	0.090	6.810	3.330	6.270	0.0473	0.35475
3 1/2	3.625	3.425	0.100	9.210	4.290	8.270	0.064	0.48
4	4.125	3.905	0.110	12.000	5.380	10.600	0.0833	0.62475
5	5.125	4.875	0.125	18.700	7.610	15.700	0.13	0.975
6	6.125	5.845	0.140	26.800	10.200	21.800	0.186	1.395
8	8.125	7.725	0.200	46.900	19.300	39.600	0.326	2.445
10	10.125	9.625	0.250	72.800	30.100	61.600	0.506	3.795
12	12.125	11.565	0.280	105.0	40.4	85.8	0.729	5.45

Table A-4 Modified correlation of grim son for heat transfer in tube banks.

	S_n/d							
	1.25		1.5		2.0		3.0	
S_p/d	C	n	C	n	C	n	C	n
In line								
1.25	0.386	0.592	0.305	0.608	0.111	0.704	0.0703	0.752
1.5	0.407	0.586	0.278	0.620	0.112	0.702	0.0753	0.744
2.0	0.464	0.570	0.332	0.602	0.254	0.632	0.220	0.648
3.0	0.322	0.601	0.396	0.584	0.415	0.581	0.317	0.608
Staggered								
0.6	—	—	—	—	—	—	0.236	0.636
0.9	—	—	—	—	0.495	0.571	0.445	0.581
1.0	—	—	0.552	0.558	—	—	—	—
1.125	—	—	—	—	0.531	0.565	0.575	0.560
1.25	0.575	0.556	0.561	0.554	0.576	0.556	0.579	0.562
1.5	0.501	0.568	0.511	0.562	0.502	0.568	0.542	0.568
2.0	0.448	0.572	0.462	0.568	0.535	0.556	0.498	0.570
3.0	0.344	0.592	0.395	0.580	0.488	0.562	0.467	0.574

Table A-5 Properties of air at atmospheric pressure.

Table A-6 ratio of N rows deep to that for 10 rows deep

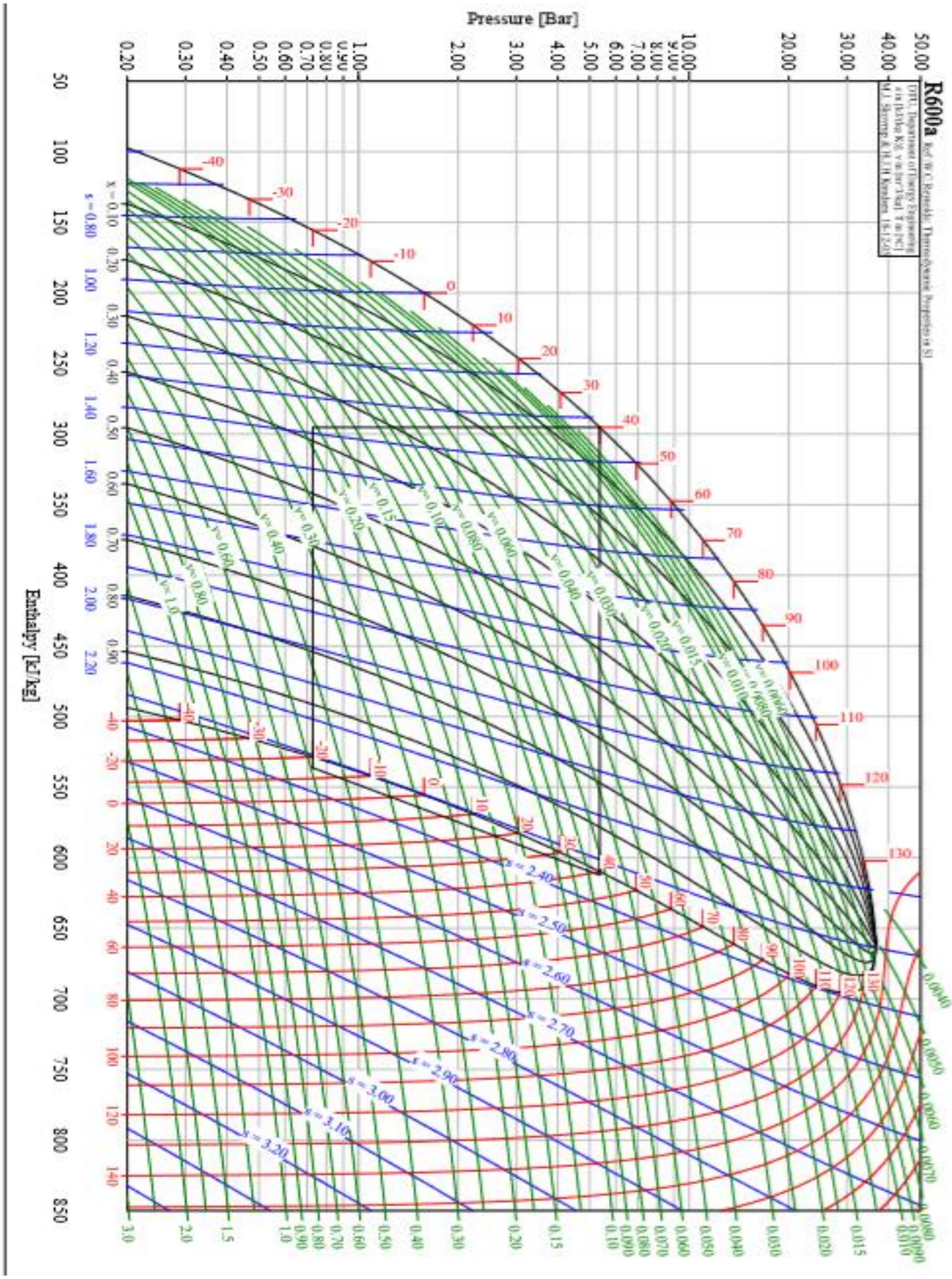
N	1	2	3	4	5	6	7	8	9	10
Ratio for staggered tubes	0.68	0.75	0.83	0.89	0.92	0.95	0.97	0.98	0.99	1.0

Ratio for in-line tubes	0.64	0.80	0.87	0.90	0.92	0.94	0.96	0.98	0.99	1.0

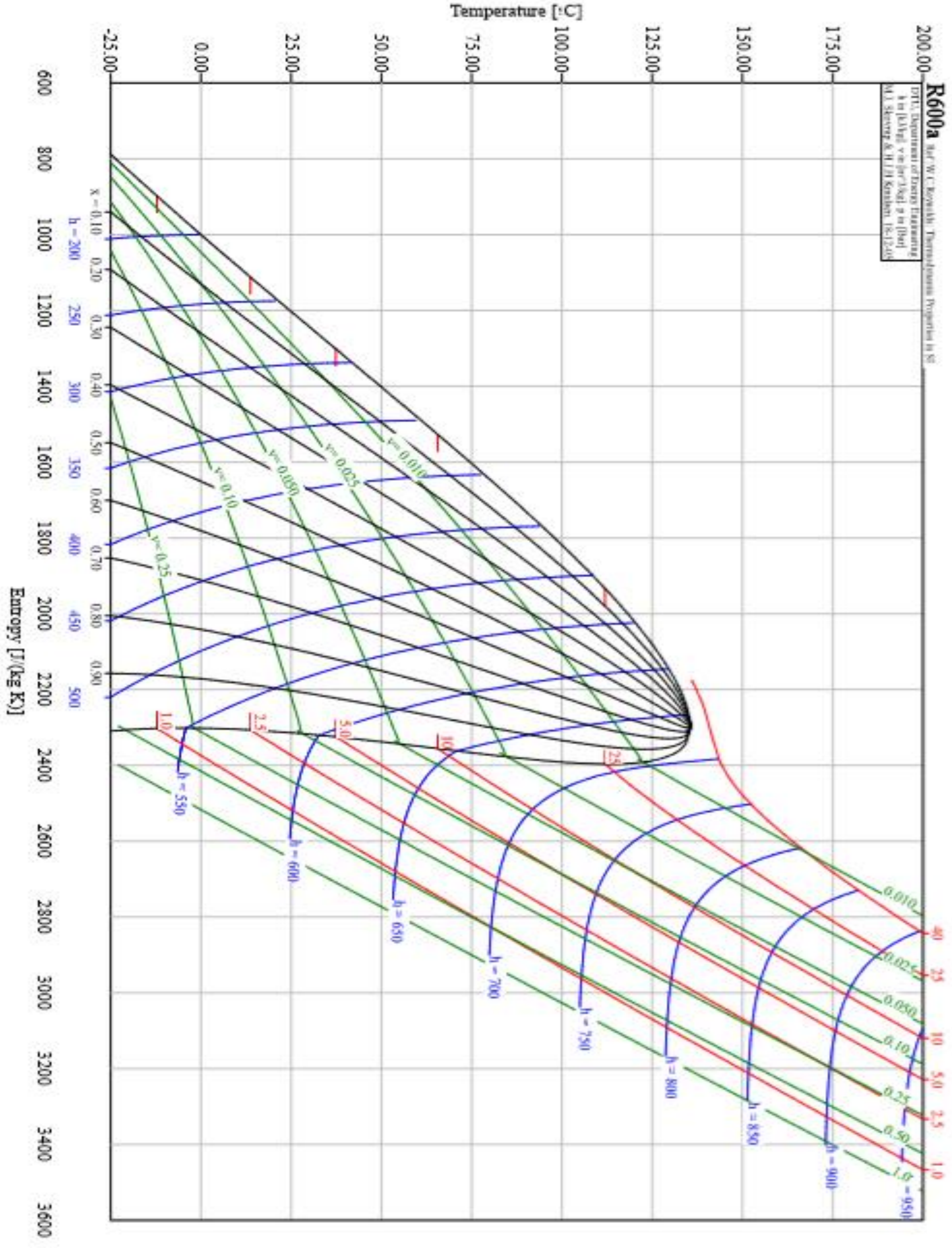
Temperature (K)	Specific Heat Capacity		Ratio of Specific Heats - k - (c_p/c_v)	Dynamic Viscosity - μ - (10^{-5} kg/m s)	Thermal Conductivity (10^{-5} kW/m K)	Prandtl Number Pr	Kinematic Viscosity[1] - ν - 10^{-5} (m^2/s)	Density1) - ρ - (kg/m^3)	Diffusivity - α - (10^{-6} m^2/s)
	- c_p - (kJ/kgK)	- c_v - (kJ/kgK)							
175	1.0023	0.7152	1.401	1.182	1.593	0.744	0.586	2.017	
200	1.0025	0.7154	1.401	1.329	1.809	0.736	0.753	1.765	10.17
225	1.0027	0.7156	1.401	1.467	2.020	0.728	0.935	1.569	
250	1.0031	0.7160	1.401	1.599	2.227	0.720	1.132	1.412	15.67
275	1.0038	0.7167	1.401	1.725	2.428	0.713	1.343	1.284	
300	1.0049	0.7178	1.400	1.846	2.624	0.707	1.568	1.177	22.07
325	1.0063	0.7192	1.400	1.962	2.816	0.701	1.807	1.086	
350	1.0082	0.7211	1.398	2.075	3.003	0.697	2.056	1.009	29.18
375	1.0106	0.7235	1.397	2.181	3.186	0.692	2.317	0.9413	
400	1.0135	0.7264	1.395	2.286	3.365	0.688	2.591	0.8824	36.94
450	1.0206	0.7335	1.391	2.485	3.710	0.684	3.168	0.7844	
500	1.0295	0.7424	1.387	2.670	4.041	0.680	3.782	0.7060	
550	1.0398	0.7527	1.381	2.849	4.357	0.680	4.439	0.6418	
600	1.0511	0.7640	1.376	3.017	4.661	0.680	5.128	0.5883	
650	1.0629	0.7758	1.370	3.178	4.954	0.682	5.853	0.5430	
700	1.0750	0.7879	1.364	3.332	5.236	0.684	6.607	0.5043	
750	1.0870	0.7999	1.359	3.482	5.509	0.687	7.399	0.4706	
800	1.0987	0.8116	1.354	3.624	5.774	0.690	8.214	0.4412	
850	1.1101	0.8230	1.349	3.763	6.030	0.693	9.061	0.4153	
900	1.1209	0.8338	1.344	3.897	6.276	0.696	9.936	0.3922	
950	1.1313	0.8442	1.340	4.026	6.520	0.699	10.83	0.3716	
1000	1.1411	0.8540	1.336	4.153	6.754	0.702	11.76	0.3530	
1050	1.1502	0.8631	1.333	4.276	6.985	0.704	12.72	0.3362	
1100	1.1589	0.8718	1.329	4.396	7.209	0.707	13.70	0.3209	
1150	1.1670	0.8799	1.326	4.511	7.427	0.709	14.70	0.3069	
1200	1.1746	0.8875	1.323	4.626	7.640	0.711	15.73	0.2941	
1250	1.1817	0.8946	1.321	4.736	7.849	0.713	16.77	0.2824	
1300	1.1884	0.9013	1.319	4.846	8.054	0.715	17.85	0.2715	
1350	1.1946	0.9075	1.316	4.952	8.253	0.717	18.94	0.2615	
1400	1.2005	0.9134	1.314	5.057	8.450	0.719	20.06	0.2521	

1500	1.2112	0.9241	1.311	5.264	8.831	0.722	22.36	0.2353	
1600	1.2207	0.9336	1.308	5.457	9.199	0.724	24.74	0.2206	

Ph diagram for R600a



TS diagram for R600a



APPENDIX B

PREUSSER SENSOR

Panasonic INSTRUCTION MANUAL

Pressure Sensor | High-performance Digital Display

DP-100 Series | For use outside Japan

MEUML-DP100 V1.1

Thank you for purchasing products from Panasonic Electric Works SUNX Co., Ltd. Please read this Instruction Manual carefully and thoroughly for the correct and optimum use of this product. Kindly keep this manual in a convenient place for quick reference.

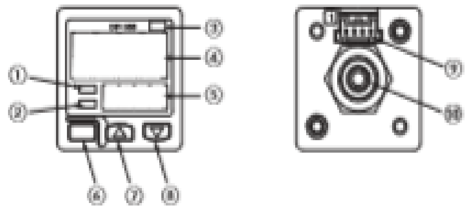
⚠ WARNING

- Never use this product as a sensing device for personnel protection.
- In case of using sensing devices for personnel protection, use products which meet laws and standards, such as OSHA, ANSI or IEC etc., for personnel protection applicable in each region or country.
- DP-100 series is designed for use with non-corrosive gas. It cannot be used for liquid or corrosive gas.
- Japanese Measurement Laws prohibit the use of this product in Japan.

1 CAUTIONS

- This product has been developed / produced for industrial use only.
- Use within the rated pressure range.
- Do not apply pressure exceeding the pressure resistance value. The diaphragm will be damaged resulting in faulty operation.
- Make sure that the power supply is off while wiring.
- Incorrect wiring will damage the sensor.
- Verify that the supply voltage including the ripple is within the rating.
- If power is supplied from a commercial switching regulator, ensure that the frame ground (F.G.) terminal of the power supply is connected to an actual ground.
- In case noise generating equipment (switching regulator, inverter motor, etc.) is used in the vicinity of this sensor, connect the frame ground (F.G.) terminal of the equipment to an actual ground.
- Do not use during the initial transient time (0.5s) after the power supply is switched on.
- Do not run the wires together with high-voltage lines or power lines or put them in the same raceway. This can cause malfunction due to induction.
- The specification may not be satisfied in a strong magnetic field.
- Avoid dust, dirt, and steam.
- Take care that the sensor does not come in direct contact with water, oil, grease, or organic solvents such as thinners, etc.
- Do not insert wires, etc., into the pressure port. The diaphragm will be damaged resulting in faulty operation.
- Do not operate the keys with pointed or sharp objects.
- Do not apply stress directly to the sensor cable joint by forcibly bending or pulling.

2 PART NAMES

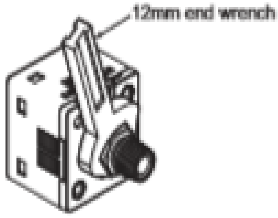


No.	Part	Description
①	Output 1 operation indicator	Lights up when comparative output 1 is ON
②	Output 2 / analog voltage operation indicator	• **Standard type**: lights up when comparative output 2 is ON • **Multifunction type**: lights up when analog voltage output is ON
③	Pressure unit display	Depending on the model, "MPa" or "kPa" appears here. If you set another pressure unit, attach the appropriate label, e.g. psi, bar, etc.
④	Main display	Large 4-character LCD display.
⑤	Sub-display	Small 4-character LCD display.
⑥	Mode selection key	For details, see page 3, section 8, SELECTING MODES.
⑦	Up key	Increases value being set.
⑧	Down key	Decreases value being set.
⑨	4-pin male connector	See "Pin assignment, 4-pin male connector" on page 2.
⑩	Pressure port	• DP-100 type: R1/8 + M5 female screw • DP-100-E type: G1/8 + M5 female screw • DP-100-M type: M5 female screw • DP-100-N type: NPT1/8 + M5 female screw

3 PIPING

Use a 12mm end wrench (14mm for DP-100-E type) when tightening a commercial coupler to the pressure port. The tightening torque should be 9.8N·m or less (M5 female connector: 1N·m or less). The commercial coupler or pressure port section will be damaged if the tightening torque is excessive.

Wrap sealing tape around the coupler when connecting to prevent leaks.



FATEK PLC

Training Box

Specification / Model		FBs-TBOX	
Case		Aluminum suitcase. Dimension is 46x32x16cm. Top cover and box body can be separated.	
Power supply		100~240VAC / 2A fuse / power switch with indicator	
PLC		FBs-24MCT(transistor output)+FBs-CM25E(Ethernet communication module)	
Programming tool	Programmer	FP-08 handheld programming panel, can develop program, monitor (optional)	
	Winproladder Programming Software	Instructor site: WinProladder with 'teaching assistant' utility	
		Student site: WinProladder	
Communication interface	Built-in	Port0	RS 232 Mini-DIN
	Communication board(CB) (optional)	Port1	RS232 or RS485 selectable, directly mounted on FBs-24MCT main unit
		Port2	
	FBs-CM25E	Port3	RS232, standard DB-9F connector
		Port4	RS485, 3-pin European terminal block
		(Port4)	Ethernet 10 Base T, IEEE 802.3 standard. Use port4 to interface PLC main unit
Input interface		Banana terminal and simulation switch with automatic and manual reset functions	
Output interface		Banana terminal, 10 points. Transistor output(Y0~Y9). All outputs buffer with discrete relay before come to terminal. Y0 and Y1 also provide a direct output terminal for high-speed pulse output (HSPSO) application.	
Expansion module (optional)		Secured by DIN Rail, 12.5cm wide slot, can accommodate three 4cm thin modules or other modules with equivalent width	
Application peripheral	Display module	4 digits 7-segment display module, attached with BCD decoding circuit	
	Thumbwheel switch	4 digits BCD thumbwheel switch module	
	Keyboard module	4 x 4 matrix keyboard module (Wiring coordinate with convenient instruction)	
	Encoder	Power supply 24VDC, 200P/R, open collector, A/B phase	
	Stepping motor	Pules/DIR control, 200P/R	
	LED display	10 of 10mmØ high-brightness LED (in red, yellow, and green), driven individually by Y0 to Y9	
Number of linked stations		Maximum 254 stations (1 station for instructor, 253 stations for student)	

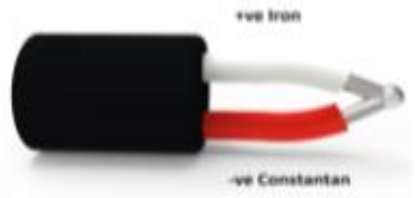
THERMO CAPLE

TEMPSENS

TYPE J THERMOCOUPLE

Type J thermocouple is a very common and general purpose thermocouple. It has smaller temperature range and a shorter lifespan at higher temperatures. It consist of positive leg made of an Iron wire and negative leg made of an Constantan (Copper-Nickel) alloy wire. Due to the Curie Point of the iron at 770 °C Type J has a limited temperature range of -40°C to 750°C.It should not be used at high temperatures in an oxidizing atmosphere as iron undergoes a molecular change and permanently loses its standard voltage output versus temperature. It does not recover when the iron is cooled. Type J has sensitivity of approx 50 microvolts/ degree C .The expenses and reliability of Type J is same as Type K. For proper working of J Type thermocouple reduction atmosphere is desired and use at low temperature is also not recommended.

J-Type



In J Type thermocouple linearity varies by -70°C over its full range from -210°C to 1200°C .It has a very straight section from 100°C to 500°C which deviates at about -0.5 °C. The lower & higher ranges can be extended with a loss in linearity.

THERMOCOUPLE CONDUCTOR COMBINATION TYPE	INTERNATIONAL COLOUR CODE TO IEC 5843:1989	AMERICAN TO ANSI/MC96.1	JAPANESE TO JIS C 1610-1981
J	+ -	+ -	+ -

Why To Prefer J Type Thermocouple:-

- Among all types of thermocouple Type J is the cheapest thermocouple.
- J Type thermocouple gives 1mV output for 18 degree C.
- Useful in reducing atmospheres.
- If J Type is protected by compacted mineral insulation and appropriate outer sheath, it is useable from 0 to 816°C, (32 to 1500°F). It is not susceptible to aging in the 371 to 538°C, (700 to 1000°F) temperature range.