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Non-Conventional Refrigeration System and Applications in Dairy and Food Industries

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Abstract:

The technology is making our environment poorly for existence, by emission of hazardous elements that causes depletion of ozone layer and global warming which affects the human comfort. A cooling and freezing are very important for dairy and food processing and its equipments and machine. In general vapour compression refrigeration system and vapour absorption refrigeration system are widely used in dairy and food for refrigeration and cooling purpose. Many Non-conventional type of cooling and freezing systems can alternatively use viz. vortex tube, pulse tube, solar based, adiabatic demagnetization, thermoelectric, LPG based, thermo acoustic, steam jet based etc. The objective of this paper is, basic of different non-conventional refrigeration system, advantages, disadvantages and application and in future can be the best replacement over conventional refrigeration systems.

KEYWORDS: Refrigeration, Rankine cycle, Vortex, Adiabatic Demagnetization, Peltier effect

1. INTRODUCTION:

Renewable & alternative non-conventional green energy technologies used for heat-pumping applications have shown real merits and received renewed interest in recent years especially in small scale portable heating applications. Refrigeration is a process in which work is done to move heat from one location to another. The primary purpose of refrigeration is producing and maintaining the temperature which is lower than that of the surroundings. The most common types of refrigeration systems use the vapour-compression refrigeration cycle. Absorption heat pumps are used in a minority of applications.

Refrigeration has many applications including but not limited to; household refrigerators, industrial freezers, cryogenics, air conditioning, and heat pumps. Cold is the absence of heat, hence in order to decrease a temperature, one "removes heat", rather than "adding cold." In order to satisfy the Second Law of Thermodynamics, some form of work must be performed to accomplish this. The work is traditionally done by mechanical work but can also be done by magnetism, laser or other means.

The temperature range of interest in refrigeration extends down to about –100°C. At lower temperatures cryogenic systems are more economical. Now-a-days refrigeration has become an essential part of food chain- from post-harvest heat removal to processing, distribution and storage. Refrigeration has become essential for many chemical and processing industries to improve the standard, quality, precision and efficiency of many manufacturing processes. Ever-new applications of refrigeration arise all the time. Some special applications require small capacities but are technically intriguing and challenging, Non-conventional refrigeration systems are required.

The Non-conventional refrigeration system works on the principle same as vapour compression refrigeration system. Instead of compressor & condenser it uses different kind of setup. In simple vapour compression system we use refrigerant for getting refrigerating effect in special purpose. There are some special methods to produce low temperatures which are Vortex tube, Pulse tube refrigeration, solar refrigeration, adiabatic Demagnetization Refrigeration, Thermoelectric refrigeration; LPG based Refrigeration System, Thermo acoustic refrigeration and Steam jet refrigeration system.

2. TYPES OF NON-CONVENTIONAL REFRIGERATION SYSTEM

2.1. Vortex Tube Refrigeration System:-

The vortex tube was first discovered by Ranque, 1933[1]. It consists of nozzle, diaphragm, valve, hot-air side, cold-air side (Fig.1). The nozzles are of converging or diverging or converging-diverging type as per the design. An efficient nozzle is designed to have higher velocity, greater mass flow and minimum inlet losses. Chamber is a portion of nozzle that facilities the tangential entry of high velocity air-stream into hot side. Generally the chambers are not of circular form, but they are gradually converted into spiral form. Hot side is cylindrical in cross section and is of different lengths as per design. Valve obstructs the flow of air through hot side and it also controls the quantity of hot air through vortex tube. Diaphragm is a cylindrical piece of small thickness and having a small hole of specific diameter at the center. Air stream traveling through the core of the hot side is emitted through the diaphragm hole. Cold side is a cylindrical portion through which cold air is passed

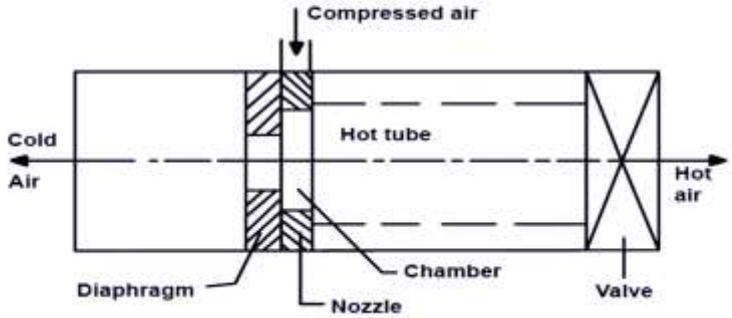

Fig.1: Schematic diagram of Vortex Tube Refrigeration System

Working: Compressed air is passed through the nozzle as shown in figure 1. Here, air expands and acquires high velocity due to particular shape of the nozzle. A vortex flow is created in the chamber and air travels in spiral like motion along the periphery of the hot side. This flow is restricted by the valve. When the pressure of the air near valve is made more than outside by partly closing the valve, a reversed axial flow through the core of the hot side starts from high-pressure region to low-pressure region. During this process, heat transfer takes place between reversed stream and forward stream. Therefore, air stream through the core gets cooled below the inlet temperature of the air in the vortex tube, while air stream in forward direction gets heated up. The cold stream is escaped through the diaphragm hole into the cold side, while hot stream is passed through the opening of the valve. By controlling the opening of the valve, the quantity of the cold air and its temperature can be varied.

There are two parameters which are controls the working of pressure tube. First is inlet pressure of compressor air & cold mass fraction. & geometric parameters & Second is material of vortex tube affect coefficient of performance (COP)[2] .

Advantages:

- It uses air as refrigerant, so there is no leakage problem.
- Vortex tube is simple in design and it avoids control systems.
- There are no moving parts in vortex tube.
- It is light in weight and requires less space.
- Initial cost is low and its working expenses are also less, where compressed air is readily available.
- Maintenance is simple and no skilled labors are required [3].

Disadvantages:

- low COP, limited capacity and only small portion of the compressed air appearing as the cold air limits its wide use in practice.

Applications in dairy and food industries:

- Waste energy recovery in boiler water preheating in dairy and food industries.
- Construct a vortex tube with maximum efficiency at minimum cost. The aim is to increase within effectiveness of merely one this kind of green technique named vortex tube used for commercial location cooling along with process cooling requirements, for instance Place cooling [4].
- Widely used in different sectors like, agriculture, transportation, domestic, industrial, food, medicine, commercial, etc [5]
- Cryogenic cooling of high value food products.

2.2. Pulse tube refrigeration (PTR):

Pulse tube refrigerant first reported in 1961 by Gifford [6]. It consist pulse tube, regenerator, valve mechanism, vacuum system and cooling system. The regenerator is main component of improving performance of pulse tube refrigerator. It is made up of bronze wire mesh. The cooling capacity of regenerator is very small, high quality thermal insulation is necessary.

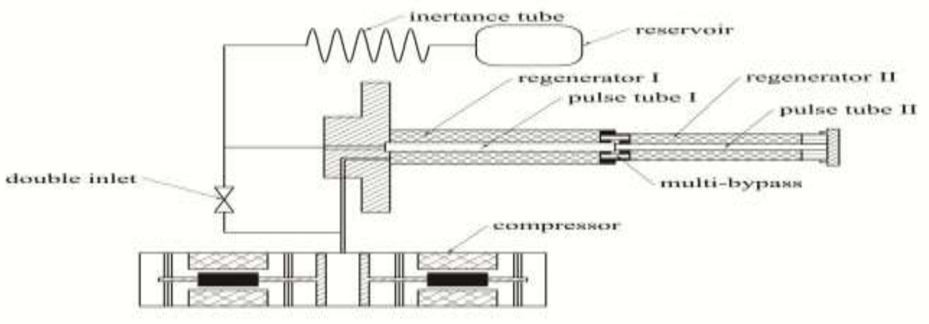

Fig.2: Schematic diagram of Pulse tube refrigeration

Working: In Pressure build up and heat rejection process valve admits high pressure gas through regenerator where air is cool. Then the gas enters the tube where act as gas piston. The gas piston compresses the gas which already present in the tube. Temperature of tube gas increases and it rejects heat to cooling media water. In pressure realizing and heat absorption process the admitted gas is connected to exhaust with the help of valve mechanism, hence gas exhausted by realizing pressure. Now expansion of tube gas take place and the lower temperature obtained at the cold end. When helium gas works as media at 25 Kg/cm^2, Gifford reported temperature at cold end is 124 K. for single stage pulse tube and 79 K at cold end for two stage pulse tube. The performance of pulse tube depend on a) Pulse Rate b) Ratio of hot end length to total length of tube. c) Temperature at cold end.

Advantages:

- Rapid improvement in cooling performance and in temperature range
- Easy and reliable cooling techniques will encourage application of low-temperature techniques.

Disadvantages:

- The coefficient of performance of PTRs at room temperature is low, so it is not likely that they will play a role in domestic cooling.

Applications in dairy and food industries:

- Refrigerator and freezer applications, including the food
- Liquefaction of gases such as nitrogen, oxygen, hydrogen, helium, natural gas
- PTRs are used as precoolers of dilution refrigerators.
- PTRs are commercially available for temperatures in the region of 70 K and 4 K

2.3. Solar Refrigeration system:

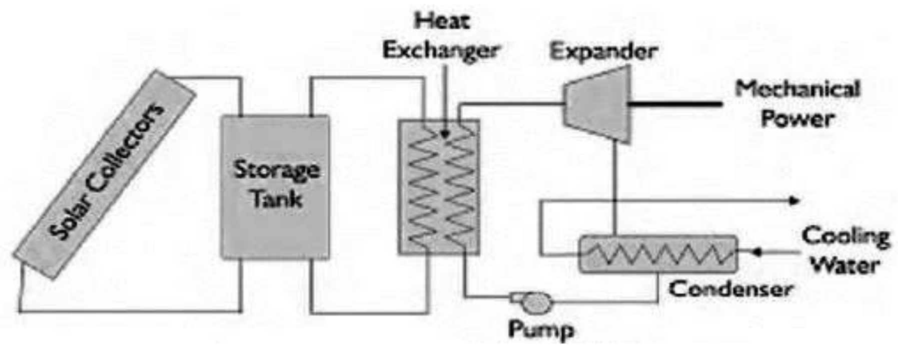

Fig.3: Schematic diagram of Solar Refrigeration system

It consist of two system first is Solar collected system and another vapour compression system as above. To run the compressor steam turbine is used to generate pressurized super-heated steam, boiler is used. To generate such type of steam parabolic collector is used. Parabolic collector collect all energy from sun and steam generated and turbine run on boiler steam. Turbine and Compressor run on turbine and VCC system works and refrigeration effect obtained in Evaporator and used for application.

Advantages:

- Environmentally friendly
- Fewer moving parts
- Low-temperature heat-driven (e.g., 55–90)
- No vibrations
- No crystallization problems
- Fewer corrosion issues

Disadvantages:

- Low COP and high manufacturing expenses

Applications of dairy and food industries:

- Refrigeration systems are also required in remote and rural areas for a wide variety of applications such as storage of milk, vegetables, fruits, food grains etc
- Thermal energy driven absorption systems have been used in some instances. Vapour compression systems that run on photovoltaic (PV) cells have also been developed for small applications.
- Dairy and Food processing, cold storage, retail, and refrigerated transport [7-8].

2.4. Adiabatic Demagnetization Refrigeration system:-

Magnetic refrigeration is based on the magneto caloric effect, discovered by E. Warburg in 1881. Similar to mechanical compression and expansion of gases, there are some materials that raise their temperatures when adiabatically magnetised, and drop their temperature when adiabatically demagnetised. Temperature very near the absolute zero may be obtained by adiabatic demagnetization of certain paramagnetic salts. Each atom of the paramagnetic salt may be considered to be a tiny magnet. If the salt is not magnetized then all its atoms or the magnets are randomly oriented such that the net magnetic force is zero. If it is exposed to a strong magnetic field, the atoms will align themselves to the direction of magnetic field. This requires work and the temperature increases during this process. If the salt is kept in a container surrounded by Helium, the heat will be absorbed by Helium. Now if the magnetic field is suddenly removed, the atoms will come back to the original random orientation. This requires work to be done by the atoms. If there is no heat transfer from surroundings, the internal energy of the salt will decrease as it does work. Consequently the salt will be cooled.

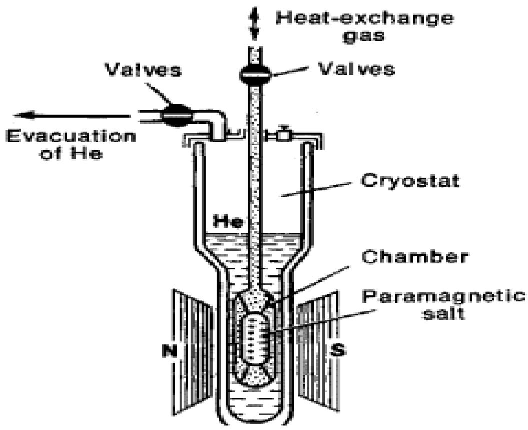

Fig. 4: Systematic diagram of Adiabatic Demagnetization Refrigeration system

This process is used to achieve temperature near absolute zero. Paramagnetic salts like gadolinium sulphate are used. Magnetization involves alignment of electronic spin. Protons and neutron also have spins called nuclear spins, which can be aligned by magnetic field. This gives lower temperatures for a brief instant of time. This is however not macroscopic temperature but temperature associated with nuclear spin.

Advantages:

- Running costs are 20% less than the conventional chillers.
- Life cycle cost is less.
- Efficiency is 60 to 70% as compared to carnot cycle.
- Maintenance free and mechanically simple construction.
- An environmentally friendly refrigeration technology, which produces no ozone-depleting gases or greenhouse gas pollution, is utilized [9].
- Magnetic materials have a higher magnetic entropy density than gas refrigerants [10].
- It has a simple machine design, such as a rotary porous heat exchanger refrigerator.

Disadvantages:

- Initial investment is more than conventional refrigeration.
- Magneto caloric materials are rare earth materials, hence availability is less,
- Permanent magnets have small magnetic fields
- Temperature fluctuations are kept to a minimum

Applications of dairy and food industries:

- Central cooling system
- Cooling in food and storage
- Domestic refrigeration systems,
- Central air conditioning systems [17].

2.5. Thermoelectric refrigeration system:-

The Thermoelectric refrigeration system is based upon the principle of thermo-electric effect, which is observed first by Henrich Lenze in 1938. This effect is based on different five laws.

Seebeck effect: "When two junctions of a pair of two dissimilar metals maintained at different temperatures, there is generation of e.m.f." [11].

$$de = \mu_{ab}.dt \quad \text{---}(1)$$

Where μ_{ab}= Seeback coefficient.

Peltier effect: "If direct current is passed through a pair of dissimilar metals there is heating at one junction, cooling at other depending upon material combinations."

$$Q = p_{ab.} I \quad \text{---}(2)$$

Where Q = rate of heating or cooling.

I = current passing through the junction.

p = Peltier coefficient.

Early in the 19th Century, Jean Peltier[12] discovered that a refrigerating power is obtained by passing current along a circuit containing dissimilar materials. Heat is absorbed at one junction of the two materials and heat is released at the other junction. Thermoelectric Refrigeration provides cooling effect by using thermoelectric effect i.e. Peltier effect rather than the more prevalent conventional methods like those using the 'vapor compression cycle' or the 'gas compression cycle'[13].

Thomson effect: It is reversible *thermoelectric* phenomenon. "When a current passes through a single conductor having temperature gradient has exhibited."

Joulean effect: "When the electric current passed through a conductor, there is dissipation of electrical energy in the form of heat."

According to Joule it is related as

$$q_j = I^2R \quad \text{---------------------------------}(3)$$

Where I= current

R= electrical resistance

Conduction effect:

"If the ends of any element are maintained at different temperatures, there is heat transfer from hot end to cold end" & it is related by

$Q_{cond} = U (T_h-T_l)$ --------------------------------(4)

Where

U = overall conductance

T_h=high temperature

T_l=low temperature

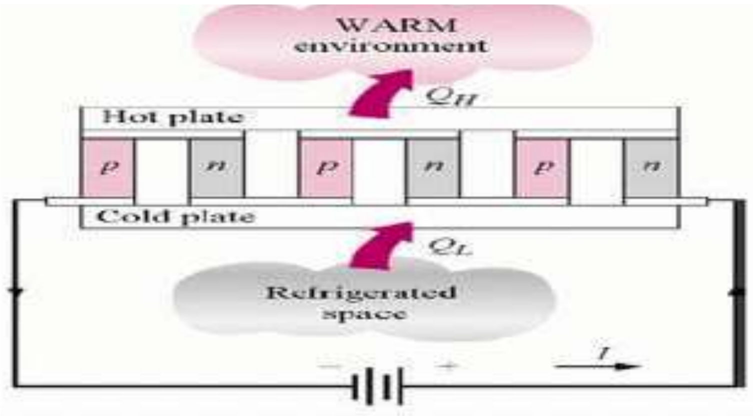

Fig.5: Schematic diagram of thermo-electric refrigeration

Working of thermo-electric refrigeration: As shown in figure.5 two different materials are connected by battery in which P-type region is connected to the positive terminal and N-type to the negative terminal. If a current is passed through them, the cooling is produced at one junction and heat is produced at other junction. If Th is maintained at ambient temperature, Tc will be lower at ambient temperature. It also to be noted that which of the junction or ends will become cold or hot depends on direction of flow of current.

COP= qc/energy supplied **= $[\mu_{ab}$ I T_l-I^2R/2-U $(T_h$-$T_l)]$/ $[\mu_{ab}$ $(T_h$-$T_l)$ I+I^2R--------------------(5)**

Where, μ_{ab}= Seeback constant, I = Current passed, R= Electrical resistance, U= Overall conductance, T_h= High temperature and T_l= Low temperature

Advantages:

- Absence of moving parts eliminates vibration problem.
- It is lighter in weight per unit mass of refrigeration.
- It is most suitable or the production cooling suit.
- Since no refrigerant is used, there is no question of toxicity environmental problem and can directly use for air condition.
- The load can be easily controlled by means of adjusting the current to meet the situation.
- Its design and manufacture is rather much simpler than the other refrigeration systems.

Disadvantages:

- The low efficiency.
- Overall COP of this system experimentally found to be 0.1 to 0.2.

Applications of dairy and food industries:

- Drinking water cooler.

- Various types of detectors, electronic equipment, portable refrigerators,
- Beverage coolers, chilled food and beverage dispensers.
- Requiring cooling devices with high reliability that fit into small spaces, powerful integrated circuits in today's personal computers also employ thermoelectric coolers.
- *Thermo-electric* devices manufacturers are expanding their production lines and are offering custom items designed and built to precise customer specifications. Cooling assemblies are being made now, using a coordinated system of heat exchangers, cold plates and even customer- supplied accessories ready to be plugged into a system by the user.
- The efficiency of the pumps and manifolds should be as high as possible with a balanced distribution of electrical power to the various sub-systems within the refrigerator.

2.6. LPG based non-conventional Refrigeration System:-

Instead of compressor & condenser we use LPG cylinder which having pressure in between 6bar-7bar for getting cooling effect. In normal refrigeration circuit we use refrigerant to get Refrigerating effect means we require to supply power to Compressor for this purpose but here inverted LPG gives the Cooling effect without any input.

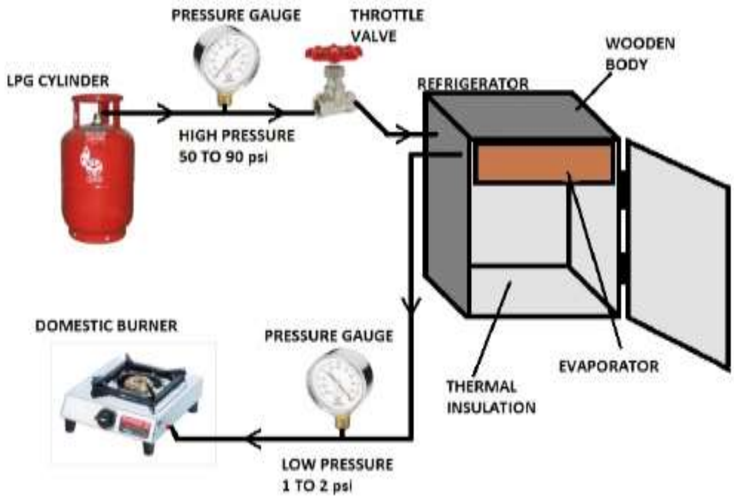

Fig.6: Systematic diagram of Solar Refrigeration system

Working principle:

First we keep the LPG cylinder in Inverted Position to get liquid at output, if you place it in normal position we get gas as output from cylinder and we not get effective cooling effect. The LPG flows control by using Regulator Valve, the function of regulator valve is to regulate the flow of LPG. Then LPG comes in refrigeration circuit via Rubber tube. In refrigeration circuit the first part is flow control valve to control the flow rate of LPG. The second part is Pressure gauge to measure the pressure **[3].**

Advantages:

- It can be used to improve combustion efficiency
- It can be run without any power
- It is usable in such places where continuous burning is the fuel.

Applications:

- It can be used to keep perishable food, cold drinks, milk etc.

2.7. Thermo acoustic refrigeration system: -

Thermo acoustic engines are thermo acoustic devices which use high amplitude sound waves to pump heat from one place to another. It is using sound waves in a pressurized gas to drive heat transfer and heat exchange. During the first process, the piston moves a thermo acoustic refrigerator consists of a tube filled with a gas. This tube is closed at one end and an oscillating device (e.g. a piston or loudspeaker) is placed at another end to create an acoustic standing wave inside the tube. To understand the thermo acoustic cycle in a thermo acoustic refrigerator, consider a parcel of gas inside the tube with a piston attached to one end of the tube (as shown in fig.7).

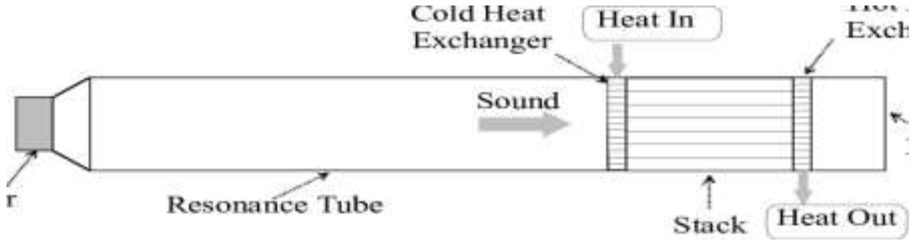

Fig. 7: Systematic diagram of thermo acoustic refrigeration

Advantages [14] ,[15]:

- There are no harmful effects of the climate
- No moving components
- Long life expectancy
- Simple and reliable
- Low fabrication cost
- There is no phase transition,
- using air or a noble gas as a working medium, which allows for more diverse applications
- Uses basic materials that do not have any special specifications
- Instead of a mechanical compressor, a thermoacoustic prime mover is used

Disadvantages:

- In comparison with traditional refrigerator technologies, it has a lower thermal efficiency

Application in dairy and food industries:

- Domestic and commercial refrigerators, freezers,
- Natural gas liquefaction.

2.8. Steam jet refrigeration system: -.

Steam jet cooling experienced a wave of popularity during the early 1930s for air conditioning large buildings. Steam ejector refrigeration cycles were later supplanted by systems using mechanical compressors.

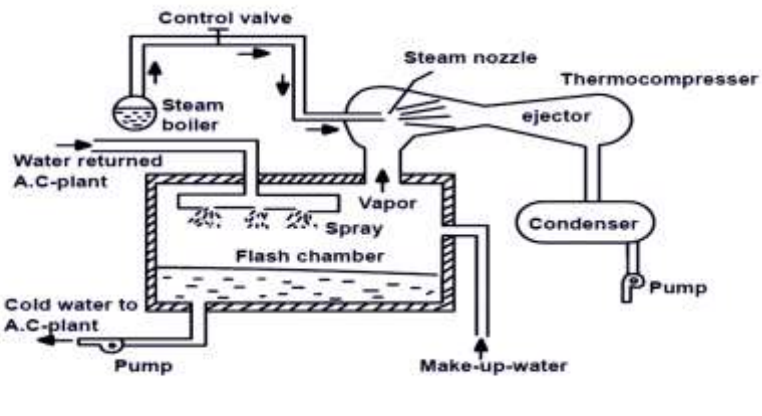

Fig.8. Systematic diagram of Steam jet refrigeration system

This system uses the principle of boiling the water below 100°C. If the pressure on the surface of the water is reduced below atmospheric pressure, water can be made boil at low temperatures. Water boils at 6°C, when the pressure on the surface is 5 cm of Hg and at 10°C, when the pressure is 6.5 cm of Hg. The very low pressure or high vacuum on the surface of the water can be maintained by throttling the steam through jets or nozzles. The general arrangement of the system is shown in the figure 8.

Working: High pressure steam is supplied to the nozzle from the boiler and it is expanded. Here, the water vapor originated from the flash chamber is entrained with the high velocity steam jet and it is further compressed in the thermo compressor. The kinetic energy of the mixture is converted into static pressure and mass is discharged to the condenser. The condensate is usually returned to the boiler. Generally, 1% evaporation of water in the flash chamber is sufficient to decrease the temperature of chilled water to 6°C. The chilled water in the flash chamber is circulated by a pump to the point of application. The warm water from the load is returned to the flash chamber. The water is sprayed through the nozzles to provide maximum surface area for cooling. The water, which is splashed in the chamber and any loss of cold water at the application, must be replaced by makeup water added to the cold water circulating system.

Advantages:

- It is flexible in operation; cooling capacity can be easily and quickly changed.
- It has no moving parts as such it is vibration free.
- It can be installed out of doors.
- The weight of the system per ton of refrigerating capacity is less.
- The system is very reliable and maintenance cost is less.

Disadvantages:

- The use of direct evaporation to produce chilled water is usually limited as tremendous volume of vapor is to be handled.
- About twice as much heat must be removed in the condenser of steam jet per ton of refrigeration compared with the vapor compression system.
- The system is useful for comfort air-conditioning, but it is not practically feasible for water temperature below 4°C.

Applications in dairy and food industries:

- Dairy and food drying plant.
- This system is particularly used in air-conditioning installations, because of the complete safety of water as refrigerant and ability to adjust quickly to load variations and no hazard from the leakage of the refrigerant [16].
- The system is particularly adapted to the processing of cold water used in rubber mills,, distilleries, paper mills, food processing plants, etc.

CONCLUSIONS:

In general vapour compression refrigeration system and vapour absorption refrigeration system are widely used in dairy and food for refrigeration and cooling purpose. Many Non-conventional types of cooling and freezing systems can alternatively use viz. vortex tube, pulse tube, solar based, adiabatic demagnetization, thermoelectric, LPG based, thermo acoustic, steam jet based etc. The objective of this paper is study of different non-conventional refrigeration system, its advantages, disadvantages and application and in future can be the best replacement over conventional refrigeration systems in dairy and food processing industries.

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