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Refrigeration for Carbonated Beverages

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Offering better quality products, better performance, better service and better price are the prime objectives of every modern industry today. Refrigeration technology is playing a vital role in achieving these objectives. Carbonated beverage industry is not an exception. Refrigeration equipment is commonly used in most carbonated beverage plants. The refrigeration load varies with plant and production capacities, from 60 tons to 600 tons.

In a typical carbonated beverage plant, refrigeration is primarily required for cooling of raw syrup during pasteurization and for cooling of beverage before filling the bottles.

Cooling of Raw Syrup

Depending upon the production schedule, adequate quantity of sugar syrup is prepared by dissolving sugar in soft water. The syrup thus prepared is called "raw syrup". Normally sugar content in raw syrup is 60 to 70% by weight. The raw syrup is first filtered in a filter press and then pasteurized in a plate heat exchanger. During this process, the raw syrup is heated to around 85 to 90°C and then immediately cooled to 25°C. The requisite dose of concentrate of desired flavor is added to the raw syrup to get "ready syrup" or "final syrup".

This final syrup is then stored in SS tanks. The final syrup is pumped to a filler room, whenever beverage is to be prepared.

General view of a 200 ton Ammonia refrigeration plant.
Photo courtesy of the author.

Low-pressure steam is used for heating the raw syrup. The cooling of raw syrup from 85 / 90°C to 25°C is achieved in two stages. In the first stage the syrup is cooled to around 42°C using cooling tower water at 32°C and in the second stage it is cooled to 25° C using either chilled water at 6°C or Propylene Glycol solution at –2°C.

Raw syrup preparation is a batch process and for smaller plants this is carried out within 2 to 3 hours and once every day. For medium size plants, more number of batches are carried out in a day. For larger plants, the timings between two batches is so short, that the cooling load is almost continuous. The raw syrup flow rate is normally fixed for a particular plant and varies with plant capacity. Smaller plants have raw syrup flow of 6,000 LPH to 8,000 LPH and larger plants have a flow of 12,000 LPH. Larger plants may have one or more raw syrup coolers. The number of batches required in a day depends upon the storage capacity of the final syrup tanks and the production schedule.

The raw syrup cooling load can be worked out as under:

$$\text{Cooling load in tons} = \frac{\text{raw syrup flow in LPH} \times \text{Sp.Ht.} \times \text{temp diff.}}{3024}$$

The product of sp. gr. and sp. ht. of raw syrup is approximately 0.85 and the syrup is cooled from 42 to 25°C. Therefore for a raw syrup flow of 12,000 LPH the cooling load will be :

$$\text{Cooling load in tons} = \frac{12000 \times 0.85 \times (42 - 25)}{3024} = 57.34$$

A safety margin of around 10% is normally added to the above load for determining refrigeration system capacity.

Beverage Cooling

The beverage is prepared by adding five times the amount of soft water as final syrup. The beverage-filling machine has controls for proportioning, mixing and carbonating so that the finished beverage has the right release of carbon dioxide gas when it is served.

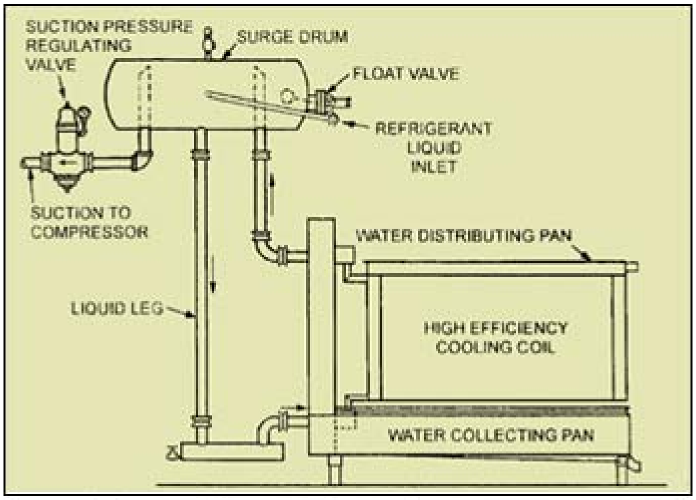
The volume of carbon dioxide dissolved per volume of product water varies with the product water temperature and carbon dioxide pressure. **Table 1** lists the volume of carbon dioxide dissolved per volume of water at various temperatures and pressures.

Table 1 : Volume of CO_2 gas absorbed in one volume of water

Temp	**Pressure in bottle in kg/cm^{2}g**						
° C	**0**	**1**	**2**	**3**	**4**	**5**	**6**
0	1.71	3.37	5.01	6.60	8.23	9.84	11.60
5	1.42	2.77	4.09	5.47	6.87	8.25	9.62
10	1.19	2.34	3.48	4.61	5.75	6.89	8.08
15	1.02	1.99	2.95	3.94	4.88	5.88	6.86
20	0.88	1.71	2.52	3.38	4.19	5.05	5.97
25	0.77	1.48	2.21	2.96	3.65	4.37	5.18
30	0.67	1.29	1.95	2.58	3.22	3.85	4.53
35	0.60	1.14	1.74	2.26	2.86	3.44	3.99

At 15°C and atmospheric pressure, a given volume of product water will absorb an equal volume of carbon dioxide gas. If the carbon dioxide gas is supplied to the product water under a pressure of approximately 1 kg/cm2g, it will absorb two volumes. For each additional 1 kg/cm^{2}g, one additional volume of gas is absorbed by the product water. Reducing the temperature of the product water to 0°C increases the absorption rate to 1.7 volumes and at 0°C, each increase of 1 kg/cm^{2}g in carbon dioxide pressure results in the absorption of an additional 1.6 volumes. Carbonated levels for different products vary from less than 2 volumes to around 5 volumes.

Normally, to avoid foaming and glass bottle breakage, it is preferred to carry out the carbonation process at lower CO_2 pressures. Therefore, to achieve proper carbonation level at lower CO_2 pressure, the beverage is chilled to around 3 to 4°C.



Baudelot Cooler. *Courtesy of ASHRAE Systems and Equipment Handbook*

Chilling of the beverage has the following advantages:

- Facilitates carbonation to obtain maximum stability of the carbonated beverage during filling (reduces foaming).
- Permits reducing the pressure at which the beverage is filled into the container (minimizing glass bottle breakage at filler)
- Reduces overall filling equipment size and investment.

In some plants the fresh water is cooled to 4°C and then mixed with the final syrup for preparing the beverage, while other plants chill the beverage after mixing.

Old beverage plants used patented direct expansion refrigeration equipment to achieve compactness, hygiene and ease of cleaning using a Baudelot-type system. However this equipment is only used for cooling of water and not the product.

Modern carbonated beverage plants use plate type heat exchangers for cooling the beverage. These heat exchangers reduce ice formation through high turbulence, which reduces the thermal gradient. Furthermore, they are hygienic and easy to clean. Such heat exchangers are normally fed with Propylene Glycol and are protected against Glycol leakage, by ensuring that the Glycol pressure is lower than the beverage pressure.

Normally, the beverage cooling load is worked out considering an entering temperature of 32°C and leaving temperature of 4°C. The flow rate of the beverage to be cooled depends upon the filler capacity.

In India, typically small plants have a single filler of capacity 240 or 400 BPM (bottles per minute) of 300 ml size glass bottle. Large plants have one or more fillers. The filler, in this case, normally has a capacity of either 600 BPM 300 ml glass bottles or 200 BPM 2 L/ 1.5L PET bottles.

The beverage flow of a typical 600 BPM 300 ml filler line is worked out as under:

Beverage flow in LPH =

Number of bottles per minute x bottle capacity in L x 60

= 600 x 0.3 x 60 = 10800 LPH

The cooling load of the above filler line can be worked out as under:

$$\text{Cooling load in tons} = \frac{\text{beverage flow in LPH} \times \text{Sp.Gr.} \times \text{Sp.Ht.} \times \text{temp diff.}}{3024}$$

The product of sp. gr. and sp. ht. of beverage is nearly 1.0 and it is cooled from 32 to 4°C. Therefore the cooling load will be as under:

$$\text{Cooling load in tons} = \frac{10800 \times 1 \times (32 - 4)}{3024} = 100$$

A safety margin of around 10% is normally added to the above load for determining refrigeration system capacity.

The beverage flow rate and approximate cooling loads for various filler capacities are shown in **Table 2**.

Table 2 : Refrigeration load for different filler capacities

Filler capacity	Beverage flow rate	Cooling load (tons)
240 BPM 300 ml glass bottles	4320 LPH	40
400 BPM 300 ml glass bottles	7200 LPH	67
600 BPM 300 ml glass bottles	10800 LPH	100
150 BPM 2 L PET bottles	18000 LPH	167
200 BPM 1.5 L PET bottles	18000 LPH	167

Type of Refrigeration System Used

The refrigeration plant is normally centralized and located in the utility area. In India, Ammonia refrigerant and single or multiple reciprocating compressors are commonly used.

Ammonia refrigerant is commonly used owing to its superior thermodynamic properties. It poses no global warming effect and is self-alarming. Ammonia refrigeration systems are much simpler, offer flexibility of operation and permit easier oil recovery.

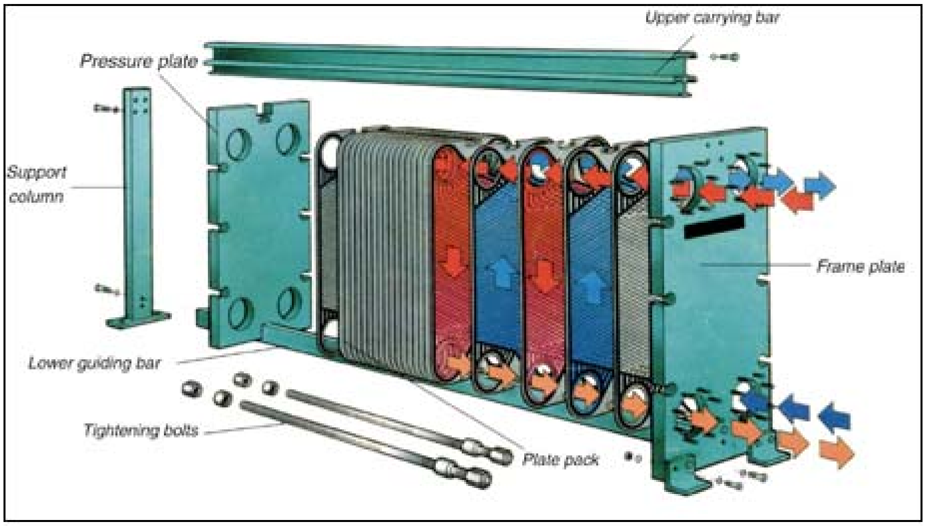
Refrigeration system for old beverage plants. In old beverage plants, a direct expansion system with Ammonia evaporating at – 4°C was normally used for beverage cooling and a chilled water system with a water temperature of 5 to 6°C was used for raw syrup cooling. This type of system was typically used for small plants with a single filler line.

The refrigeration system in this case, comprises of two compressors, one catering to the direct expansion evaporator in the filler section and one catering to the water chilling system for the raw syrup cooler. The high side equipment such as the condenser and receiver as well as the cooling tower is common for both systems.

The water chilling circuit comprises of a chilled water tank, primary pumps, secondary pumps and interconnecting piping with thermal insulation. The chilled water tank has two compartments, a cold well and a hot well. The water from the hot well is circulated by the primary pumps through the chiller, where it gets chilled, and sent to the cold well. The water from the cold well was circulated through the raw syrup cooler by secondary pumps and returned to the hot well. The temperature rise across the raw syrup cooler is around 5 to 6°C.

The direct expansion system of the filler machine comprises of a Baudelot-type heat exchanger or a plateand- tank arrangement or tank and coil arrangement for chilling the water. The beverage is prepared after the water is chilled. In all these three arrangements, the Ammonia liquid is fed to the evaporator by the thermosiphon principle from a surge vessel provided on top of the evaporator. To avoid water freezing, an evaporator pressure regulator is often provided on the suction side of the surge vessel.

Such a system, though energy efficient, may pose operational difficulties due to frequent stoppage of the filler operation for various reasons such as bottle breakage, sanitation, operation, etc. Further, Ammonia leakage, if any, in the production hall can create a lot of discomfort for the production staff. Finally, such a system lacks the flexibility of operation in case of multiple filler lines.



The plate heat exchanger. Courtesy of Alfa Laval (India) Limited.

Refrigeration system for modern beverage plants. In modern plants an indirect cooling system is used. The filler machine has a plate-type heat exchanger for cooling of beverage to around 4°C by using the secondary coolant at around –2°C. For this purpose an aqueous solution of Propylene Glycol is used. Addition of Propylene Glycol reduces the freezing point of water. Normally, 30% Propylene Glycol solution by weight with a freezing point of –12.6°C is used. Glycol is preferred over brines and alcohols, because of its low volatility and corrosivity when properly inhibited. Propylene Glycol is less toxic than Ethylene Glycol. Commercial food-grade quality Propylene Glycol is available for such applications.

For small plants with one filler line, of capacity 400 BPM and below, the refrigeration load is around 100 to 120 tons. In this case a single Glycol chilling system of 100 to 120 ton capacity is used. Normally, a stand-by compressor is preferred.

For medium size plants, with one filler line of capacity 600 BPM, the refrigeration load is around 180 to 200 tons and two Glycol chilling systems each of 90 to 100 ton capacity are used.

For large capacity plants with multiple filler lines, normally, the refrigeration load varies from 400 to 600 ton capacity and a Glycol chilling system with multiple packages, each of either 100 or 200 ton capacity are used.

Earlier, the Ammonia condenser and chiller used to be of the shell and tube type. During the last ten years, semi-welded plate type heat exchangers have been increasingly used as condensers and chillers in refrigeration plants.

The plate heat exchanger consists of a plate pack with alternate channels and traditional gasketed channels. The refrigerant flows in welded channels, whereas cooling water, in case of condenser and fluid to be cooled in case of evaporator, flows in the gasketed channels.

The plates, typically of SS316 stainless steel, are usually configured with a wave pattern, which results in high turbulence and low susceptibility to fouling. The plate corrugations not only give strength and rigidity but also greatly increase the rate of heat transfer.

These plate heat exchangers have several benefits over conventional shell and tube vessels, such as :

Smaller refrigerant volumes. The internal holding volume of the plate type heat exchanger is very low as compared to shell and tube type heat exchanger. This results in a smaller refrigerant charge (5 to 20%).

Easy access for maintenance and inspection. In the twin plate heat exchangers the liquid heat transfer surfaces are readily available for cleaning.

Thermal efficiency. High heat transfer coefficients resulting from the intense turbulence in the plate channels and reduced fouling tendencies, because of the high wall shear stress, makes PHEs more efficient. Plate heat exchangers can be designed to have closer approach temperatures i.e. higher evaporating temperature and lower condensing temperature to achieve higher COP.

Flexibility. Should process conditions necessitate major changes in the refrigeration load or water flow rate, the semiwelded plate heat exchangers can be modified or extended to meet these new capacities, simply by addition or deletion of plates.

Resistance to stress. When clamped together in the frame, the corrugated plates are in metallic contact with each other, which provides a rigid construction, able to withstand vibrations. In case of shell and tube heat exchangers, there is a possibility of failure of the tube or tube-to-tube sheet joint because of flow-induced vibrations and refrigerant leaks on to the process fluid. No such possibility exists in the case of plate heat exchangers and therefore these can be used to chill hygienic fluids, eliminating secondary refrigerants.

If a plate heat exchanger accidentally freezes, there will be no damage to the plates or to the sealing system.

Glycol Circuit (please refer to the P&I diagram)

The glycol tank is located in the Utility area. The glycol tank has two compartments, a cold well and hot well. Glycol at –2°C from the cold well is circulated through the process heat exchangers, viz. beverage cooler and raw syrup cooler, by secondary pumps and returned to the hot well. The glycol picks up heat from the beverage and the raw syrup in the respective heat exchangers and gets heated to around 6°C. The glycol flow through these process heat exchangers is normally controlled by a temperature controller and a three-way bypass control valve provided near the heat exchanger. The glycol from the hot well at 6°C is circulated by the primary pumps through the chiller, where it gets chilled to –2°C and sent back to the cold well.

Ammonia Refrigeration Circuit (please refer to the P&I diagram)

The glycol is chilled in PHE (Plate Heat Exchanger) chiller from 6 to –2°C by liquid Ammonia evaporating at –6 to –7°C on the other side of the plate. The liquid Ammonia is fed from the surge drum through the PHE chiller by the thermo-siphon principle. Thermo-siphon means circulation, owing to density difference between fluids in two connecting legs, one hot and one cold. The wet vapors formed in the PHE chiller travel to the surge drum and exits the nozzle horizontally and the liquid droplets, if any, get separated from the Ammonia vapors. The compressor sucks the vapors from the surge drum. Ammonia liquid level is maintained in the surge drum, in response to the evaporation rate, by means of a liquid level controller and liquid line solenoid valve.

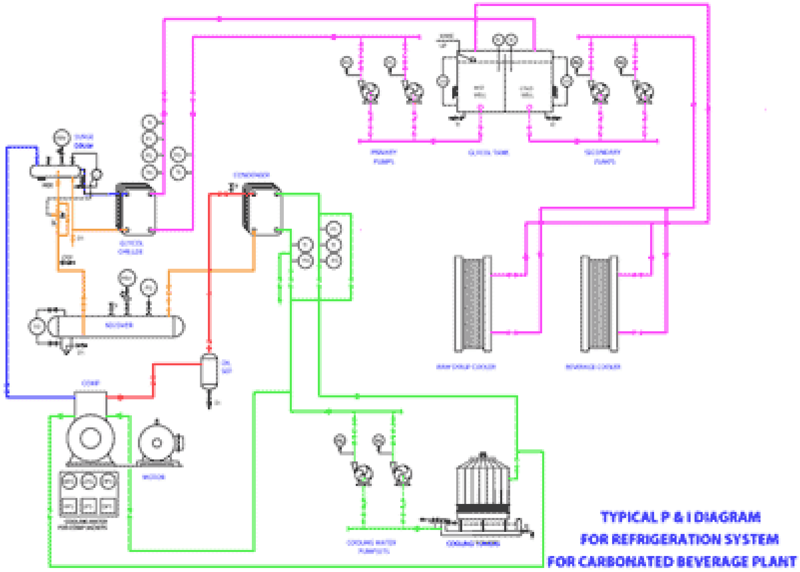
The compressor raises the pressure of the low pressure Ammonia gas from the surge drum to condensing pressure. High pressure Ammonia gas from the compressor goes to the condenser via an oil separator. Oil separator has an impingement plate and baffles to change the direction of the gas. When the Ammonia gas travels through the oil separator, majority of the oil carried along with the gas gets separated.

In the condenser, Ammonia gas is condensed by exchanging heat with the cooling water and Ammonia liquid is drained into the Ammonia receiver. In the condenser Ammonia gas first gets de-superheated to saturation temperature and then condensed at 40°C.

Ammonia liquid from the receiver goes to the surge drum via an expansion valve, where it is expanded to low-pressure liquid before entering the surge drum.

Cooling Water Circuit (please refer to the P&I diagram)

The cooling water flowing on the other side of the plate picks up the heat from Ammonia gas and gets heated from 32 to 36°C. The cooling water pumps take water from the cooling tower basin, circulate through the condensers and return to the cooling towers. A small portion of the cooling water is used for providing jacket cooling of the refrigeration compressors.



**TYPICAL P & I DIAGRAM
FOR REFRIGERATION SYSTEM
FOR CARBONATED BEVERAGE PLANT**