and the latent heat at saturation temperature is about 120 Btu per lb. The refrigerant for liquefying the compressed gas (usually ammonia or Refrigerant 12) should be at about −28 F to effectively condense the CO_2. Nearly all moisture must be removed from the compressed gas; this may be done by passing it through a horizontal-blow finned-coil located in a cold (36 F) cellar which condenses out about 80 percent of the moisture, the condensate being drained from the system. Further removal is effected by flowing the gas through desiccant dryers. The emerging gas has a slightly higher temperature but with a dew point around −45 F. Thus conditioned, the gas is then liquefied by contacting the liquefying surfaces which are kept ice free because of the low moisture content of the gas, assuring continuous service. The dryers are installed in duplicate with automatic timing for regeneration of the desiccant material. The current use of desiccant dryers replaces the earlier method which used dual sets of double pipe dryers in which the moisture was frozen out and retained in the heat exchanger, and uses the liquid CO_2 as the refrigerant. Frequent de-icing by alternating the liquefiers was required with this type system.

Liquefiers are of the vertical shell-and-tube, inclined double-pipe or the shell-and-tube types. The refrigerant side is operated fully-flooded with the refrigerant being supplied from the main plant with a booster compressor discharging into the plant suction main.

CO_2 Storage and Re-evaporation

The condensed CO_2 drains into a storage tank, which is usually designed for 300 psig working pressure and varying in size for storage capacities of 10,000 to 50,000 lb each. The vessel is enclosed in an insulated box and is equipped with equalizing connections, safety valves, liquid-level indicator or try-cocks, and electric heating units. Tests are regularly made for gas purity from samples withdrawn from above the liquid level.

As liquid is withdrawn from the tank it is introduced into a steam-heated liquid evaporator which is automatically controlled to give the desired superheat to the re-evaporated gas. This type is gradually replacing other types because of its ability to control the temperature of the re-evaporated gas very closely. The evaporated gas is then temporarily stored in buffer tanks until needed in the brewery and bottle house.

HEAT BALANCE

Most of the steam required for processing, water heating, and general plant heating can be obtained as a by-product. Because the manufacture of beer is a batch process with various peaks occurring at different times, the study of the best heat balance possible is rather involved. In a given plant it depends on many variables and a comprehensive study of all factors is of utmost importance.

In plants which produce in excess of 300,000 bbl annually, the steam turbine as a prime mover comes into prominence. A bleeder type operating at 400 psig can be used to drive a refrigeration compressor, electrical generator, or both, and steam bled therefrom for process and other needs requiring lower pressure steam. In a smaller plant, a less favorable heat balance must be accepted in line with a more economical plant investment program. Each brewery requires its own individual study in order to procure the most economical equipment consistent with the cost of further economies.

PART II: WINE MAKING

Refrigeration requirements for wine making can be divided into two classifications: (1) that needed for control of temperature during fermentation, and (2) that needed to hasten the removal of the excess potassium bitartrate and cold coagulable materials in newly made wine and cold coagulable materials from brandy. The purpose of the refrigeration, and the methods and equipment used, differ radically under these two classifications.

The class of wines produced, the amount of grapes crushed, the size, shape and construction of the fermenting tanks, and marketing practices are some of the factors which must be considered. An exact evaluation of the refrigeration load for a particular winery can only be arrived at through careful study of that winery's wine-making methods and marketing practices.

Wine-making methods undergo continual development in keeping abreast of technological advances. Refrigeration is an accepted step in present practice with its benefits fully recognized by management. An expanded usage for cold stabilization or chill-proofing cannot be forecast, however, as ion-exchange appears about to gain wider application for producing tartrate stability. Their comparative effectiveness in producing wine stability, cost of processing both fixed and operating, will ultimately decide this issue. For many wine types, it appears at present that the ion exchange process used in conjunction with refrigerated storage can markedly reduce the holding time required but cannot wholly supplant low temperature storage because some cold coagulable materials are not removed by ion exchange treatments. In some dry white wines, on the other hand, attainment of stability has been claimed by ion exchange alone.[1]

Cooling Requirements of Fermentation

Wines are greatly affected by the temperature of fermentation. High temperatures (above 100 F) during fermentation inhibit the growth of wine-yeasts, but favor the growth of disease-producing bacteria. Control of temperature is a basic wine-making problem. Refrigeration to dissipate a large fraction of the heat generated during fermentation is deemed necessary in all hot wine-making regions.

Enologists have reported[2] a positive correlation between the organoleptic quality of young red table wines and the fermentation temperature, and a negative correlation for young white table wines, within the range 55 to 85 F. For best results, more cooling must be provided for white than for red table wines. Industry experience indicates that red wine fermentations should not exceed about 85 F, and white wine fermentations about 60 F. Uniform control of the fermentation temperature now appears more desirable than the semi-controlled fluctuating system widely used.

The transformation of sugar to alcohol is exothermic. The amount of heat generated during the fermentation of a gram molecule of sugar is not known precisely, but the value of 23.5 kg cal determined by Bouffard[3] is commonly used. One pound of sugar, therefore, produces 234 Btu, and each percentage of sugar by weight generates enough heat in fermenting to raise the temperature of its solution 2.34 F. Since degrees Balling or Brix equals percentage sugar by weight, it follows that for every degree Balling that a *must* (crushed grapes) decreases during fermentation, sufficient heat is produced to raise the entire mass 2.34 F. Thus, a must of 24 Balling in fermenting is capable of generating enough heat to raise its temperature $24 \times 2.34 = 56$ F. Such a must, commencing fermentation at 70 F, would reach the inactivation temperature for the yeast (100 to 105 F) while it still contained 10 percent fermentable sugar, provided no heat losses occurred during this period.

Much of the heat generated during fermentation is lost by radiation and convection. Field experiments indicate that about 50 percent of the overall heat generated is so dissipated. The exact amount depends upon many factors such as the size, shape, and material of which the fermenter is constructed, the surrounding air temperature, but more importantly upon the rate of fermentation which is temperature dependent. Recent work[3] indicates the fermentation reaction, under controlled temperature conditions, to have a temperature quotient that ranges from 1.42 to 2.64 depending upon the variety of grape studied. Under practical conditions the amount of heat loss during the initial stages of fermentation (first half-step) is closer to 33 percent than the overall 50 percent indicated previously. Calculated cooling requirements for fermentation should be based upon this figure.

Assuming average conditions (grapes with a concentration of approximately 24 Brix at 70 F) and existing practices, the minimum cooling requirement for fermentation of table wines is 150,000 Btu per 1000 gal of must. Grapes of higher sugar concentration (more than 24 Brix) or with more field heat (more than 70 F) require 250,000 Btu per 1000 gal, or 50,000 Btu per ton.

The above values are too high for dessert winery practice. The amount of sugar allowed to ferment differs greatly for the various dessert wine types produced. Under average conditions, the cooling requirement for fermentation of dessert wines should only amount to 50 percent of those cited previously.

The minimum cooling requirements for fermentation of table wines under conditions of constant temperature, which is advocated by some enologists, are estimated to be 225,000 Btu per 1000 gal at present. A value of 400,000 Btu per 1000 gal should be used for grapes of higher sugar concentration (more than 24 Brix) or with more field heat (more than 70 F). Load calculations for this plan of operation under dessert winery practice should only be attempted after a thorough study of a detailed operating program.

In a winery crushing 50 tons of grapes per day for table wines there will be on the average about 10,000 gal of must to be cooled daily. This will require refrigeration facilities capable of removing 2,500,000 Btu in the time period chosen by the winery operator. If cooling operations are carried out on a 12 hr basis, about 208,000 Btu per hr of refrigeration will be required. Water in the amount of 2500 gal per hr rising 10 F deg in temperature will satisfy the required refrigeration load. Most wineries are situated where they can obtain water at 60 F in adequate quantities, or where water from a cooling tower will approach 60 F. Units employing water as the cooling medium are therefore the most commonly used devices for this purpose.

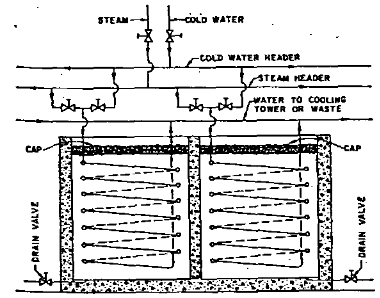

Fig. 3 .... Cooling Coils in Concrete Fermenters

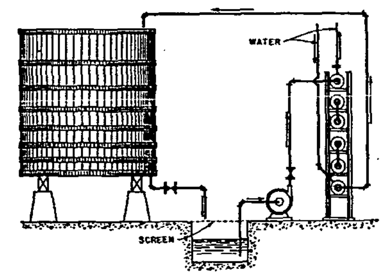

Fig. 4 .... Cooling Fermentations with External Shell-and-Multitube Cooler

This tendency to use water as the cooling medium has persisted even where the cooling load cannot be adequately furnished by the available water supply or by water from a cooling tower. Extreme flexibility is the principal advantage. The refrigerating capacity of the available water is increased by lowering its temperature. Storage reservoirs assist to satisfy the required refrigeration load. Recently high efficiency, mechanically refrigerated water coolers have been used to supplement the refrigeration capacity when fermentations are conducted at temperatures below that obtainable with the available water supply. Existing refrigeration facilities frequently are diverted to the same purpose.

Methods of Cooling Fermentations

Systems using water as the cooling medium may be divided roughly into those in which the cooling coils are mounted directly within the fermenters (Fig. 3), and those in which the fermenting must is pumped through external heat exchangers counter-current to the direction to cooling water (Fig. 4). The former method is most commonly used by the dessert wine industry while the latter is used most frequently in the wineries producing table wines.

Red and black grape varieties acquire a cap of skins and berry tissues during fermentation and consequently require different treatment from fermentations of white grape varieties. The cap of a red grape fermentation requires a twice daily pushing under the surface of the fermenting liquid (punching) for color extraction, and to dissipate the excessive amount of heat that develops just above the liquid surface, i.e., inside the cap layer. Temperatures from 10 to 20 F deg higher than that prevailing in the main volume of the liquid are normal.

The relative success of the system of placing coils in the fermenting tank developed concurrently with the adoption of modern electrically powered pumps and the use of concrete for construction of fermenter tanks. Twice daily pumping-over replaces manual punching. Pumping is continued until all the excess heat of the cap is removed. The concrete construction permits permanent installation of the coils in the fermenter. They are mounted about one foot away from the side walls, and centrally positioned with respect to height of the side wall. Water, which is either wasted or recirculated over a cooling tower, is allowed to flow continuously during the first 48 hr or until the must reaches 5 Balling.

Location of the coils in the fermenting tanks is a matter of