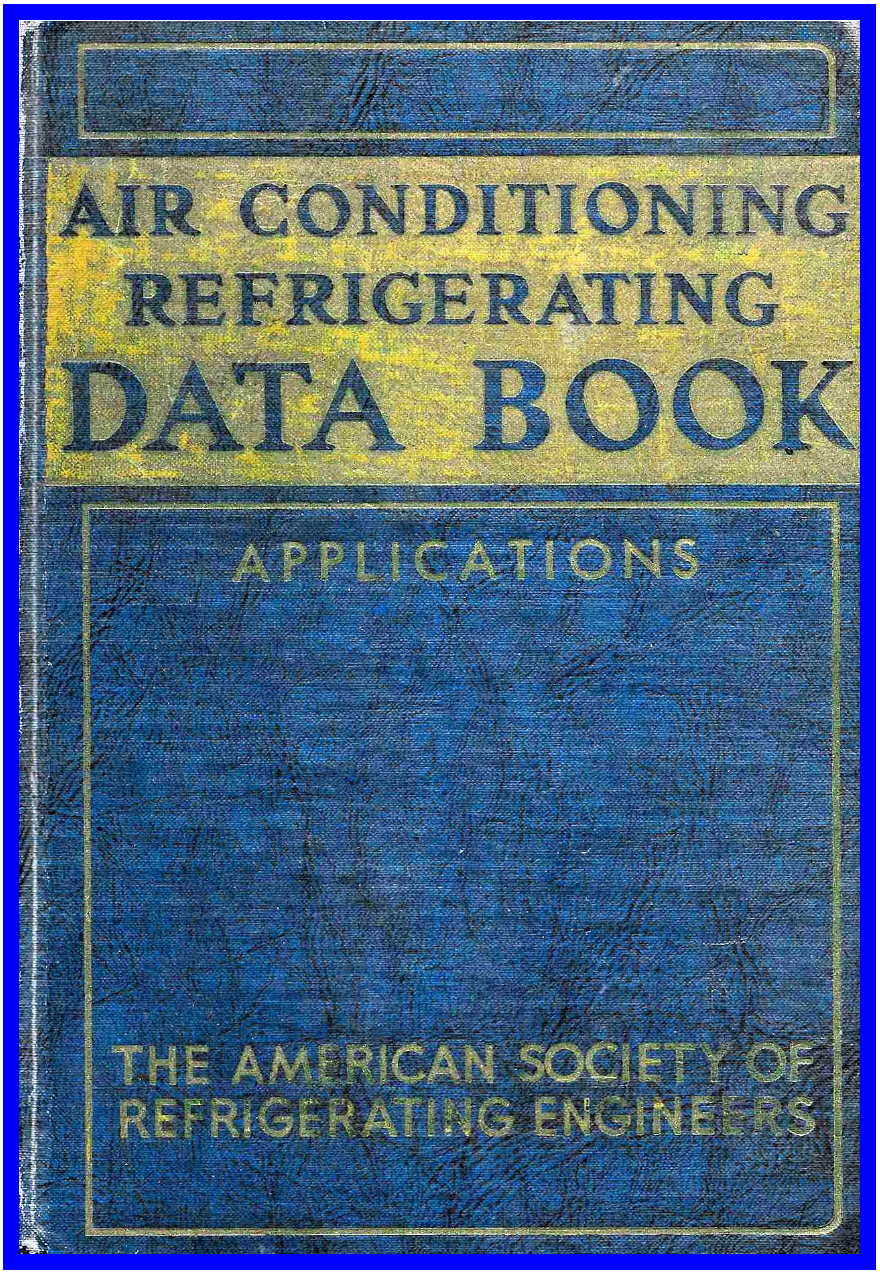
Refrigeration in American Breweries 1860-1920



Breweries

REVIEW FROM ASRE 1954-55 USING DATA FROM 1930s

14. BREWERIES

THE brewing of beverages made from malted cereals can be traced to antiquity. Historians record the wide usage of such beverages made from grain in Babylon and Egypt as early as 6000 B.C. Thousands of years were to pass, however, before Pasteur unlocked the laboratory door that permitted the first understanding of the phenomenon of beer, which is the result of a fantastic interaction of living organisms. This new knowledge indicated that the control of these organisms was a requisite for a stable and consistent product, and that they could be best controlled by means of improved sanitation and temperature control. Natural ice was used extensively, but it was not until the introduction of mechanical refrigeration in the latter part of the 19th century that any definite improvement in beer making was possible. Improved techniques were quickly adopted by the industry.

Chemical Aspects

Two distinct types of chemical reactions are used in the brewing of beer. In the first, which is carried out in the brew-house at temperatures of above 70 F, the starches in the grains are converted into sugar. This reaction is brought about by first crushing the malt and suspending it in water by means of agitation in the mash-tun. A portion of the malt is cooked separately with an adjunct, usually corn or rice. This mixture, after cooking, is then combined with the main malt mash which has been so proportioned that a combining temperature of 160 F results. It is at this temperature that the diastase contained in the malt splits all of the starch ($C_6H_{10}O_5$) present in the grain, converting it into sugar maltose ($C_{12}H_{22}O_{11}$) by enzymatic action. The enzyme diastase which induces this chemical reaction is not consumed, acting merely as a catalyst. Some of the maltose is subsequently split by another enzyme, maltase, into glucose ($C_6H_{12}O_6$).

After the mashing and after a suitable period of rest during which the reaction is completed, the sweet wort is drawn from the grain into the kettle. After boiling with hops, it is then quickly cooled and transferred to the starting cellar, where yeast is added to induce fermentation. A flow diagram is shown in **Fig. 1.**

Fermentation, which is carried out under refrigeration, is a chemical reaction converting maltose ($C_{12}H_{22}O_{11}$) into ethyl alcohol (C_2H_5OH) and carbon dioxide (CO_2) according to the following equation:

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 4C_2H_5OH + 4CO_2$$

The heat evolved in the reaction is 280 Btu per lb of maltose converted. The quantity of ethyl alcohol and carbon dioxide produced can be calculated by considering their molecular weights. The molecular weight of maltose is 342; of ethyl alcohol, 46; of carbon dioxide, 44. One pound of maltose will form:

$4 \times 46/342 = 0.538$ lb of ethyl alcohol
$4 \times 44/342 = 0.515$ lb of carbon dioxide

Two types of yeast are used: the **bottom fermentation** type is used in the fermenting of **lager beer;** whereas the **top fermentation** type is used in the making of **ale.** They are so called because after fer-

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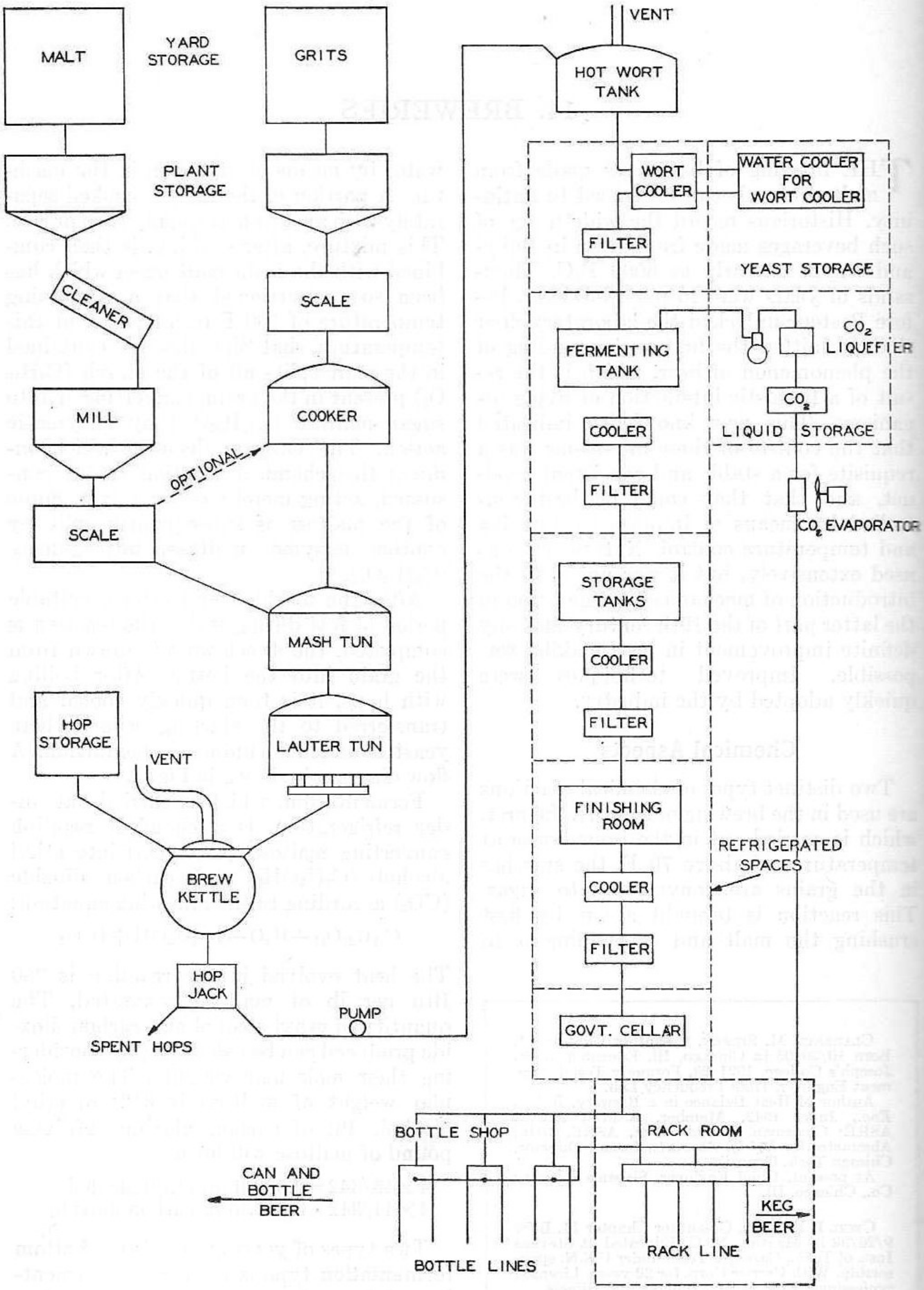


Fig. 1. Brewery Flow Diagram.

mentation, one settles to the bottom and the other rises to the top. A more significant difference between the two types is that in the top fermentation type, the fermenting liquid attains a higher temperature before a continued rise is checked. Because of these higher temperatures, the sugars are fermented to a greater degree, resulting in a higher alcoholic content in ale and also yielding a fermentation which imparts a flavor character distinctive to it. With the bottom fermentation yeasts, fermentation is carried on between 45 to 55 F; while with the ale type, the temperature may go as high as 70 F. In either type the temperature during fermentation would continue to rise above that desired but is checked by cooling coils or attemporators through which ice water or brine is circulated. Usually these attemporators are manually controlled.

Wort is weighed by the saccharometer, which is a hydrometer calibrated to read percent of solids as maltose in solution with water. The standard instrument is the Plato saccharometer, and the reading is referred to as **percentage of solids by saccharometer,** or **degrees Plato. Table 1** illustrates the various data deducible from a reading of the saccharometer.

The same instrument is used to check the progress of the fermentation. While it still gives an accurate measure of density of the fermenting liquid, it is no longer a direct indicator of dissolved solids, because the solution now contains alcohol which is lighter than water. This variation in saccharometer reading is called the **apparent attenuation,** which is always greater than the **real attenuation.**

In engineering computations, 81% of the apparent may be considered a close approximation of the real attenuation. Thus, 81% of the difference between the solids shown in Table 1 for saccharometer readings before and after fermentation would represent the weight of maltose fermented. This weight in pounds times 280 Btu gives the heat of fermentation in Btu per barrel. The difference between the original solids and weight of fermented solids gives the residual solids per barrel. It is to be assumed that there is no change in the volume due to fermentation. The specific heat of beer may be assumed to be the same as that of the original wort, the weight per barrel, however, being decreased according to the apparent attenuation.

Processing

Wort cooling.

To prepare the boiling wort from the kettle for fermentation, it must first be cooled to a temperature of about 45 to 50 F. To avoid contamination with foreign organisms which would adversely affect the subsequent fermentation, this cooling must be done as quickly as possible, especially through the temperatures around 100 F. Besides the primary function of wort cooling, other beneficial effects accrue that are essential to good fermentation. These include precipitation, coagulation of proteins, and oxidation due to natural or induced aeration depending upon the type of cooler used.

In the past, the Baudelot type of cooler was almost universally used because it was inherently easily cleaned and afforded the necessary aeration of the wort. The present trend, however, is away from this type

Table 1. Total Solids in Wort, lb per bbl

Saccharometer readings in % solids	Specific gravity	Weight per bbl.		Specific heat Btu per lb
		Total	Solids	
0	1.0000	258.7	0.00	1.000
1	1.0039	259.7	2.60	.993
2	1.0078	260.7	5.21	.986
3	1.0118	261.8	7.85	.979
4	1.0157	262.8	10.51	.972
5	1.0197	263.8	13.19	.965
6	1.0238	264.9	15.89	.958
7	1.0278	265.9	18.61	.951
8	1.0319	267.0	21.36	.944
9	1.0360	268.0	24.12	.937
10	1.0402	269.1	26.91	.930
11	1.0443	270.2	29.72	.923
12	1.0485	271.2	32.55	.916
13	1.0528	272.4	35.41	.909
14	1.0570	273.4	38.28	.902
15	1.0613	274.6	41.18	.895
16	1.0657	275.7	44.11	.888
17	1.0700	276.8	47.06	.881
18	1.0744	277.9	50.03	.874
19	1.0788	279.1	53.03	.867
20	1.0833	280.2	56.05	.860

of cooler. A modified form of the Baudelot, consisting of a series of swinging leaves encased within a removable enclosure into which sterilized air is introduced for aeration, has replaced a good number of the older type. Also coming into increasing favor are coolers of the totally enclosed type, including the double pipe, shell and tube, and the plate types. Air for aeration is admitted under pressure into the wort stream, usually at the discharge end of the cooler. The air is first filtered and then irradiated with bactericidal radiation, or it can be sterilized by heating in a double-pipe heat exchanger with steam. By the injection of 0.167 cu ft of air per bbl of wort, which is the amount necessary to saturate the wort, a normal fermentation should result. The quantity can be increased or diminished accurately as the subsequent fermentation will indicate.

The coolant section of wort coolers is usually divided into two or three sections. For the first section, a potable source of water is drawn upon. The heated effluent goes to a hot water tank where, after additional heating, it is used for succeeding brews. Final cooling is done in the last section, either by direct expansion or by means of an intermediate coolant such as chilled water or propylene glycol. A third section may be used between these two from which the warm water can be recovered and stored in a **wash-water** tank for later use in various washing and cleaning operations around the plant.

The old procedure of using a large surfaced tank called a **Kuehlschiff,** into which the wort is pumped directly from the kettle via the hop jack, is being abandoned. In the Kuehlschiff, the wort was permitted to cool from about 190 to 160 F, during which time the traub would settle to the bottom, and the wort became partially aerated. The clear wort would then be drawn from the top of the liquid, leaving behind considerable wort with the traub. The residual traub and wort were subsequently transferred to storage tanks for further settling to recover the entrained wort. Among the reasons for the discontinuance of the Kuehlschiff, the following are the most important:

1. Large space requirements
2. Possibility of contamination
3. Ceiling condensation, and the possibility of its contaminating the wort from dripping
4. Cost of the investment in, and operating of, the necessary air-conditioning equipment it required
5. Loss of wort in the traub
6. The investment in storage tanks and equipment necessary to recover part of the entrained wort

Diatomaceous earth filters are now being used. The entire brew is pumped through these filters, resulting in a brighter and more sterile wort than was possible by settling.

Closed coolers save space and expensive cooler room air conditioning equipment. They also permit a faster cooling rate and provide accurate control of the degree of aeration. The problem of cleaning plate coolers is solved by having a spare set of plates ready for weekly replacement. The cleaning between successive brews is accomplished by circulating cleaning and/or sterilizing solutions through the cooler.

In selecting a wort cooler, the following points should be considered:

1. Sanitation and the ease with which these conditions can be maintained with a minimum of cost
2. Minimum cost for refrigeration, for the temperature of the wort to be brought as near to the available water temperatures as is practicable
3. Adequate heat transfer surfaces utilizing water and consistent with the cost of water
4. Maximum heat recovery consistent with overall plant heat balance

Some breweries use the open type Baudelot wort coolers. However, they are no longer generally accepted in the industry. In this type of cooler, the wort flows by gravity over the outside of horizontal pipes arranged in stands. The cooling medium flows successively through pipes from bottom to top, giving a step-by-step approximation to counterflow. The tubes using water as a cooling medium are of copper or some alloy inert to wort; the tubes using ammonia or brine are polished steel or alloys inert to wort. A distributing trough at the top of the cooler permits the wort to flow over the outside of the tubes. The cooled wort is collected in a broad shallow pan at the bottom. All surfaces are exposed for easy cleaning and are thoroughly cleaned after each brew. To avoid contamination, the cooler is placed in a closed room through which clean washed or filtered air is circulated.

The size of wort coolers is determined by the rate of wort cooling desired, the rate of water flow, and the temperature differences employed. A brew, which may vary in size from 50 to 700 bbl and over, is ordinarily cooled in from two to four hours. Open type coolers are made in stands up to about 20 ft in length. Where more length is needed, two or more stands are operated in parallel.

Open coolers are best operated with a wort flow of from three to three and a half barrels per hour per lineal foot of stand. At higher rates there is a tendency to splash, and the height (number of tubes per stand) becomes excessive, requiring increased refrigeration. The coefficient of heat transfer varies with the velocity of water in the tubes and the flow of wort over the tubes.

Fermenting cellar.

After cooling, the wort is pitched with yeast and collected in a fermenting tank, where fermentation sets in according to the chemical reaction previously outlined. For each 31 gal bbl of wort, about 25 lb of solids are converted. The daily rate of conversion varies, depending on the operating procedure adopted in each plant. A representative rate might be, on the first day, two pounds of maltose converted. The rise in temperature caused by fermentation increases this rate to seven pounds on the second day. By now the maximum desired temperature has been attained and a further rise is checked by means of an attemporator, so that on the third day another seven pounds is converted, which rate continues on through the fourth day. By now the amount of unconverted maltose remaining in the beer is much diminished, and because of the inhibiting action of alcohol and carbon dioxide on further yeast propagation, the action nearly halts on the fifth day when only about three pounds are converted. Because of the decreased rate, the temperature of the beer begins to drop and by the sixth day further fermentation has been checked. It is then cooled to 29 F, filtered, and transferred to the stock cellar. Complete fermentation can generally be effected in about seven days.

Attemporators usually consist of one or two rings of four inch copper tubing, concentric with the walls of the tank and supported at about two-thirds of the height of the liquid. The agitation necessary for heat exchange between the attemporator and the beer is provided partly by convection, but principally by the ebullution set up by the CO_2 bubbles rising to the surface of the liquid. In estimating the heat transfer surface required, a heat transfer rate of 15 Btu per sq ft per hr per F has been found to be reasonable. The heat loss from tank walls and surface of the liquid may be disregarded in calculating the attemporator coil surface requirements.

The refrigeration requirements are necessarily based on the maximum volume of wort in fermentation at one time. **Fig. 2** illustrates this load based on a 500 bbl per day production rate. The days are represented by the ordinate, and the pounds of solids converted per day by the abscissa. The individual brews in fermentation on any particular day are additive. For example, on the fifth day brew no. 1 is finishing with a conversion rate of 3 lb for that day; brew no. 5, which is just beginning the fermentation cycle is fermenting at the rate of 2 lb; while brews no. 2, 3, and 4 are at the maximum rate of 7 lb per bbl per day each. The total solids fermented on this day is thus seen to be 26 lb per bbl for the 2500 bbl in fermentation, making a total of 13,000 lb of solids converted. Since the heat of fermentation is 280 Btu per lb, the refrigeration load would be $13{,}000 \times 280/24 \times 12{,}000$, or 12.6 tons.

About 13 lb of CO_2 are generated for each barrel of beer fermented, most of which is collected and liquefied for later use in the brewery for carbonating, for counter pressure in transfer operations, and for the bottling lines.

Adequate fresh air must be provided in

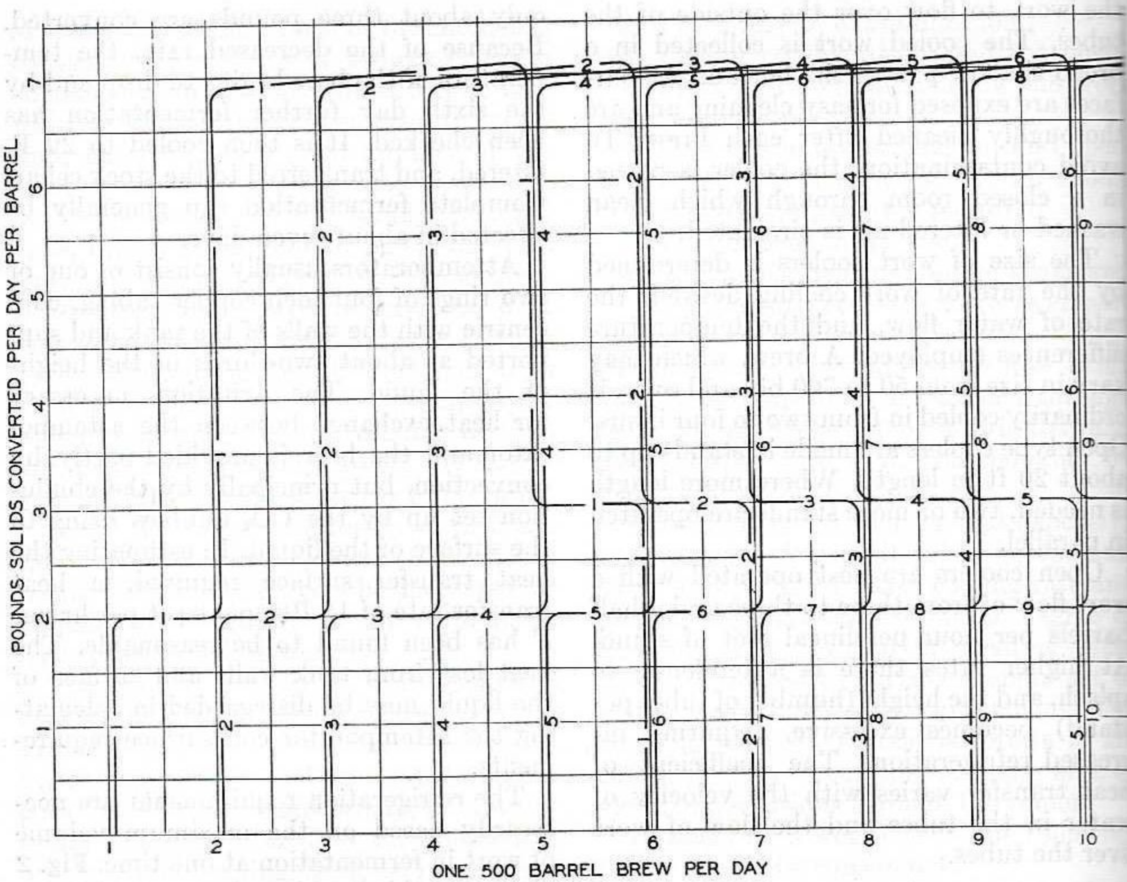


Fig. 2. Solids Conversion Rate.

Brew 5	2 lb×500 bbl=	1000 lb
Brew 2	7 lb×500 bbl=	3500 lb
Brew 3	7 lb×500 bbl=	3500 lb
Brew 4	7 lb×500 bbl=	3500 lb
Brew 1	3 lb×500 bbl=	1500 lb
	26 lb.	13,000 lb

the fermenting cellar to safely dilute the CO_2 emanating from the fermenters. The amount permissible should be such that there is no health hazard to the men working in these spaces. Concentrations below one percent are considered entirely safe. Increasing amounts reduce the efficiency of the worker and concentrations of four percent make the performance of work for protracted periods untenable. Since it is heavier than air, CO_2 tends to settle to the floor from where it may be withdrawn by means of scupper connections at the floor level. Fresh air may be introduced through the ceiling, the openings being located so as not to remove or disturb the layer of protective CO_2 gas on top of the fermenting beer.

Stock cellar.

The stock cellar is a refrigerated room containing tanks into which the cooled and filtered beer from the fermenter is transferred for the purpose of aging and settling. New filtering methods have obviated the need for settling, as all suspended solids are removed during the transfer from the fermenter. The retention of beer in the stock cellar is a matter of the brewer's discretion and may be from three weeks to three months. Cellar conditions desired and the elements contributing to the refrigeration load are indicated in **Table 2.**

While the CO_2 pollution of the air in the stock cellar is far less than in the fermenting room, adequate provision must be made to supply fresh air in sufficient amounts to keep the concentration below one percent.

Finishing cellar.

In the finishing cellar the beer is polished by filtration, and is then carbonated by any of a number of different methods. The filtering is usually done through a series of cellulose pulp filters, the number of filters used depending on the brilliance desired in the finished product. After this final processing, it is transferred to the racking room for filling into kegs, or to the government cellar for bottling.

Kraeusen cellar.

Instead of the usual carbonating method, some brewers prefer to carbonate by means of the Kraeusen method, for which a Kraeusen cellar is substituted for the finishing cellar. This cellar contains a number of tanks capable of retaining a pressure of about 20 psig. Because the retention period is from seven to fourteen days, a greater capacity is required here than in the case of a finishing cellar. In transferring beer from the stock cellar, it is blended with about 20% of beer that had been brewed only a few days prior and which is just coming to the Kraeusen stage of fermentation. By sealing the tank, the evolved CO_2 gradually builds up a pressure to the desired point at which time it is relieved by a closely regulated relief valve. This pressure will give the proper CO_2 retention in the liquid and is dependent on the temperature of the beer. The quantity of gas dissolved is a direct function of pressure and the inverse function of temperature.

Heat is generated by this secondary fermentation, but the temperature of the liquid does not rise to as high a temperature as it did in the fermenter because the fermentable sugars are only available from the 20% which has been added as Kraeusen. Furthermore, the bulk of the liquid had a lower starting temperature, having come from the stock cellar at about 29 F. A temperature of from 42 to 44 F may be reached at the peak, after which the liquid cools to the ambient temperature of the

Table 2. Factors in Cooling Loads of Refrigerated Rooms

	Wort cooling room	Fermenting cellar	Stock cellar	Racking room	Govt. cellar	Hop storage	Yeast storage
Refrigeration loads due to:							
Insulation	x	x	x	x	x	x	x
Air changes	x	x	x				
Workmen	x	x	x	x	x	x	x
Lights	x	x	x	x	x	x	x
Tanks		x	x	x	x		
Infiltration	x	x	x	x	x	x	x
Wash water	x	x	x	x	x		x
Motors	x	x	x	x	x	x	x
Heat of fermentation		x	x				
Conditions to be maintained:							
CO_2 removal		x	x				
Air motion	x	x	x	x	x	x	x
Temp, F	50	50	31	32	31	31	50
Relative humidity, %				50		50–60	80
Wood tanks							
open		80					
closed		70	80		80		
Steel tanks							
open		80					
closed		50	50		50		
Concrete tanks							
open		80					
closed		50					

room. This cooling can be accelerated in the tanks by means of attemporators through which a brine such as propylene glycol is circulated. Since additional heat is generated, the calculations for the refrigeration required include that of lowering the liquid temperature from 44 to 29 F and maintaining this temperature for several days to coagulate any chill-hazing proteins that may have been introduced in the Kraeusen. These coagulated proteins are retained in the filter when the beer is finally transferred to the racking machine or to the government cellar.

Storage

Hop storage.

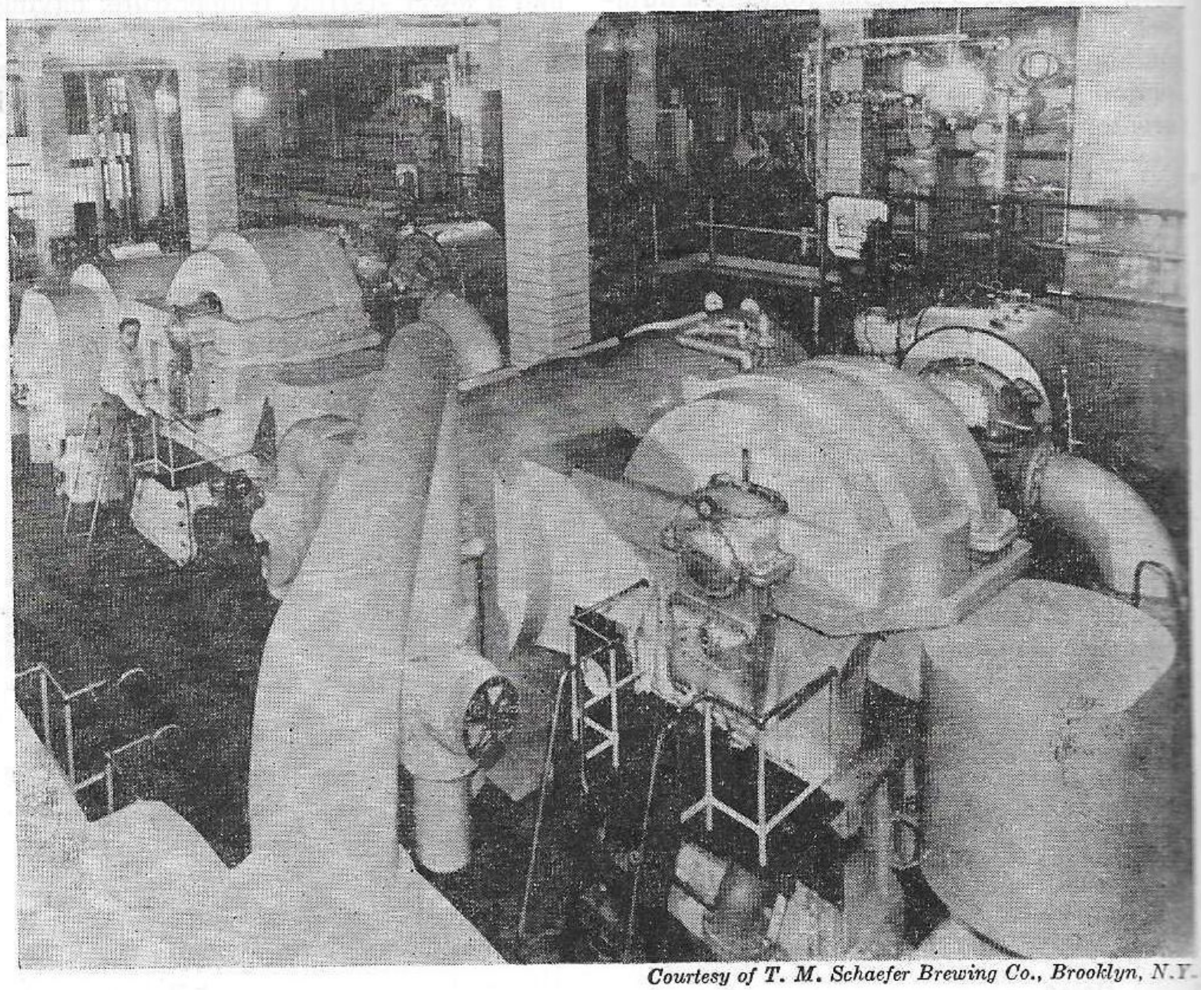
Hops should be stored at a temperature of from 29 to 32 F with a relative humidity of from 50 to 60% and with very little air motion, to prevent excessive drying. Sweating of the bales should not be permitted, as this would carry off the light aromatic esters which would deteriorate the fine hop character.

Yeast culture room.

In the yeast culture room, yeast is propagated to be used in re-seeding and replacing yeast that has lost its virility. A relative humidity of 80% is required to prevent the yeast from hardening on the vat walls. The CO_2 blanket on top of the vats should not be disturbed by excessive air motion.

CO_2 storage.

The CO_2 required for final carbonation and for transfer operations is in most cases collected from the fermenters and is stored until needed. Both gaseous and liquid storage is being used, but the latter presents a great advantage in the smaller



Courtesy of T. M. Schaefer Brewing Co., Brooklyn, N.Y.

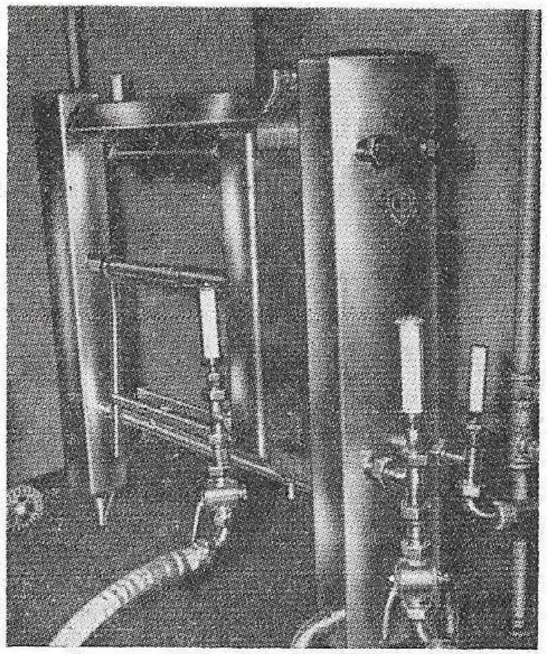
Fig. 3. Centrifugal Compressor Room—View of Ammonia Condensing System.

space required for storage. To liquefy the gas, it is first thoroughly washed, after which it is compressed to 250 psig. Then it is cooled by refrigeration to condense the gas to a liquid and is stored in steel tanks in a well insulated room. Usually this room is cooled by the evaporation of the liquid CO_2, the evaporated gas being recycled by reliquefying and again being returned to the storage tank. A small booster compressor is used to liquefy the CO_2, the discharge of the booster being introduced into the main refrigeration plant suction line. The volume for liquid storage is about 1/46 that required for storage in the gaseous state. The purification of the gas is an added advantage resulting from liquefaction, since fractional distillation eliminates undesirable gases such as air, etc., which liquefy at different temperatures. The CO_2 thus stored is relatively uncontaminated.

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 and/or electrical generator, 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.



Courtesy of Kiewel Brewing Co., Little Falls, Minn.

Fig. 4. CP Stainless Steel Multi-Pass Beer Cooler.

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If you searched this chapter for something which was not found in it, please let the editors know.