Refrigeration in American Breweries 1860-1920

History of the Brewing Industry

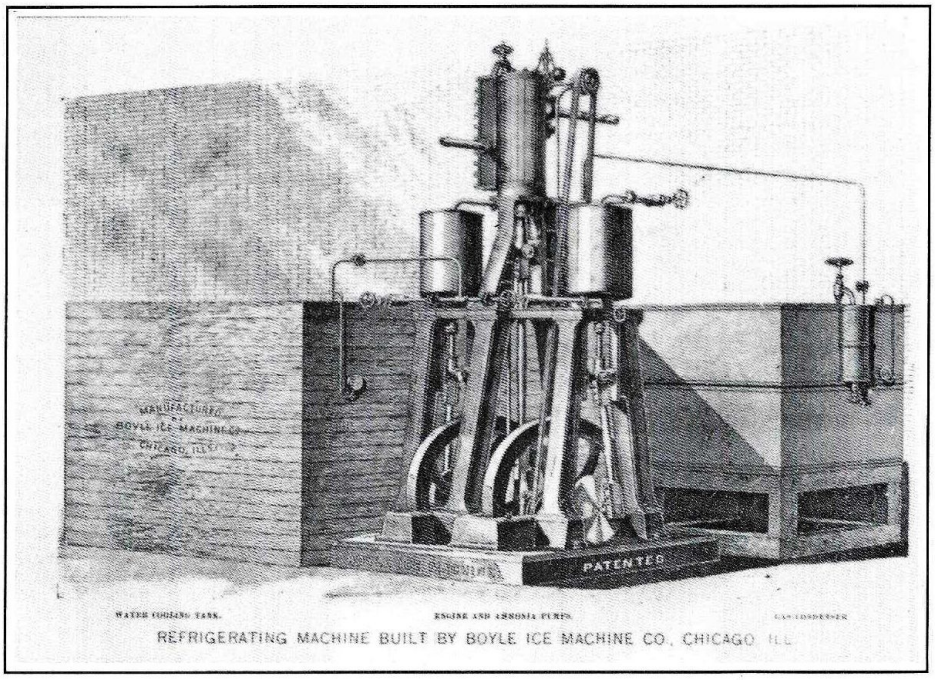


Figure 8-33 *Refrigeration machine for breweries, etc., as manufactured by the Boyle Ice Machine Co. in the 1880s (from catalog,* Boyle Ice Machine Co. Patentees and Manufacturers of Refrigerating Apparatus and Ice Machines, *Chicago, c. 1881).*

From the book *HISTORY OF THE BREWING INDUSTRY AND BREWING SCIENCE IN AMERICA*
Dr John E Siebel & Anton Schwarz, Chicago 1935

History of the Brewing Industry and Brewing Science in America

Prepared as Part of a Memorial to the Pioneers of American Brewing Science

Dr. John E. Siebel *and* Anton Schwarz

Begun by the late
JOHN P. ARNOLD
Completed by
FRANK PENMAN

CHICAGO, ILLINOIS
UNITED STATES OF AMERICA
1933.

Brewing Becomes a Great Industry

IN 1864 the production of beer was 3,141,381 barrels of 31 gallons and the population of the United States was about 35,000,000. That makes a per capita consumption of beer of about 2.75 gallons in the year.

In 1914—half a century later—when beer production reached its highest point, the production was 66,189,473 barrels of 31 gallons and the population was about 98,500,000. That makes a per capita consumption of beer of about 20 gallons in the year.

This enormous increase both in total production and in per capita consumption can be well followed by means of a table which has been here compiled for the purpose.

It is a new feature in the statistical history of the brewing industry to have these figures here tabulated in comparison with the number of breweries operating each year and with the population of the country. The comparison thus presented affords an instructive and intensely interesting outlook over the history of the business forward from about the point when the chronological calendar comes to an end.

It will be seen in this novel table how the production and consumption of beer increased much faster than the population until in 1914 the per capita consumption was more than seven times that of 1863.

During the same period the per capita consumption of whiskey was reduced from 2.55 gallons to 1.40 gallons a year. There can be no question that the increased beer consumption was one of the chief influences that brought about this advance in habits of temperance of the American people. No better proof could be desired to controvert the assertion of the prohibitionists that beer drinking leads to whiskey drinking. In beer, alcohol is merely a spice, in whiskey it is a dominant drug.

In a very condensed form, this table tells the story of the industrial development of the brewing industry. It remains only to put a little flesh on the skeleton, to round out the form and call attention to some of the salient features.

The plan followed in the history of the pre-industrial period up to 1864 cannot be followed here. It would be impossible to even mention all the breweries that were started or to pursue the growth of those which lasted over from the pre-industrial period into the era when brewing became one of the biggest industries of the country with a capitalization estimated at $800,000,000 in itself and about a billion when the auxiliary lines of business are added. It must suffice

So, in giving a rapid survey of the development of brewery practice and technic in America it will be helpful to pick out certain conspicuous improvements which stand out by their radical differentiation and their technical and scientific progressiveness and their deep-reaching modifying or even revolutionizing influence.

As such high points of the development of brewing practice and technic we mention the following:

1.—The introduction of steam power.

2.—Modification of the mashing process by machinery and instruments of precision and the perfection of raw grain mashing, leading ultimately to

3.—The development of the American infusion process of mashing which contributed largely to the creation of the American type of beer.

4.—Steam boiling of the wort, better extraction of the hops, and sterile cooling of the wort with artificial refrigeration.

5.—Mechanical refrigeration, enabling accurate maintenance of temperatures in ventilated, above-ground rooms and permitting brewing the year around.

6.—Introduction of pure culture yeast, enabling close control of fermentation.

7.—The extensive use of unmalted grain, at first pre-cooked separately, later prepared for direct addition to the malt mash.

8.—Scientific control of brewing operations and materials.

9.—Pneumatic malting, giving complete control of the malting process.

10.—Bottle beer—virtually a new industry.

11.—Electric power.

At times, fans were used to hasten the cooling. Notwithstanding the heat and vapors given off by the wort which served for a time to protect it, the process was an invitation to infection. As early as 1800 a device was constructed to cool the wort by running it through pipes immersed in cold water after preliminary cooling on the surface cooler. Iron cooling vats helped to accelerate the cooling process later in place of wooden ones. Spraying or atomizing devices came into partial use by which the hot wort was scattered over the surface cooler, being both cooled and aerated. A similar effect was aimed at by running the wort over a screen.

Primitive pipe coolers were speedily superseded by the Baudelot cooler, a system of horizontal pipes arranged parallel one above the other. The wort was discharged on the top pipe and ran down over the several pipes into a gutter at the bottom. The pipes were charged with a cooling medium, cold water in the upper part and brine or ammonia in the lower ones. In some cases these coolers and aerators were enclosed in glass cabinets filled with filtered air. Another cooling device was invented to be attached to the hopjack. The wort was forced through pipes surrounded by a cylinder through which flowed a counter-current of a refrigerant, while filtered air aerated the wort.

None of the advances made in the technical development of the brewing industry in the latter half of the nineteenth century was of greater importance than the advent of mechanical refrigeration. Cooling and keeping cool are essential in the production of beer, from the malting and storing of the materials to the cooling of the wort, the maintenance of low temperatures in fermentation, in storage, in racking, in bottling. In the early times brewing was a regional and a seasonal business. In America it could not gain a footing in the Southern States on account of the warm climate, until mechanical refrigeration arrived. In the Northern States brewing was practically confined to the winter months, two kinds of beer being made, one for immediate use, one for use in the summer, the latter being stored in cool places, mostly under ground or in hillsides. In later times, ice houses were built above ground and filled with natural ice which was used for cooling in the warm season. In some cases salts were added to the ice to increase its cooling power. Quite an elaborate ice house was erected for the brewery of E. W. Voigt in Detroit in 1880, according to a patented system.

It was mechanical refrigeration that made brewing a year around business and allowed the various operations to be conducted in accordance with the requirements established by scientific research as to cooling and exact maintenance of low temperatures. It was mechanical

refrigeration that permitted all the parts of the brewing process to be carried on above ground and thus made possible the erection of the magnificent brewery structures that were wont to grace our cities.

It was a process of mutuality between the brewing industry and the refrigeration industry. From its very inception the refrigeration industry received perhaps the most powerful support from the brewers who were keenly alive to the advantages that the new industry would eventually offer them. Inventors of refrigerating devices were given opportunities by brewers to try their machines, and many were the failures in the early days for which the progressive brewers paid heavily. But refrigeration developed rapidly under this influence until it came to fulfill all the requirements of the brewer and enabled him to respond to the needs of an ever increasing demand for his product. It was the introduction of lager beer, naturally, that contributed chiefly to this development, the quick-use top-fermentation beers of earlier times having no such exacting requirements in the matter of refrigeration.

It is not intended here to give a complete and detailed history of the development of mechanical refrigeration. Its intimate connection with the brewing industry, however, calls for the presentation of the high-lights of its rapid growth.

As a curiosity of history it may be stated that the first brewery in the world to install a refrigerating machine was that of Glasgow & Thunder, of Bendigo, Victoria, Australia. This was an English machine, based on the use of ether.

The origin of the modern ice machine is ascribed to F. P. A. Carré, a Parisian, who employed the property of certain gases of permitting themselves to be liquified under pressure, and absorbing heat, thus producing cold, when allowed to expand, according to a principle first formulated by Faraday. Carré employed aqua ammonia.

The first machine for mechanical refrigeration in the United States was installed in 1869 by George Merz, a brewer of New Orleans, who used the invention of the Frenchman Charles Tellier. It was a compression machine employing methylic ether. Later it was remodeled for the use of ammonia. The first Carré machine in the United States was installed by S. Liebmann's Sons Brewing Company at Brooklyn, New York, in 1870. It was only moderately successful.

Considerable progress was made by the machine designed by Franz Windhausen, of Brunswick, Germany, who after using air and sulphuric acid finally arrived at the use of carbonic acid gas and a compression device. His first American machine was erected in the brewery of Christian Moerlein, of Cincinnati, in 1875.

The Bergner & Engel Brewery of Philadelphia in 1877 installed a machine designed by Daniel L. Holden which was abandoned be-

cause the chemical employed (chimogene) was considered dangerous by the insurance companies.

A machine of the absorption type was patented by Thomas L. Rankin and installed in a number of breweries, principally in the South, around 1880, the first one, however, going into the brewery of Jacob Ruppert, of New York.

Brewery refrigeration entered upon a more substantial footing with the introduction of the machine invented by Daniel Boyle, whose first ammonia compression machine was erected in the brewery of Bemis & McAvoy in Chicago in 1877. Shortly after, Boyle machines were installed by the Ferd. Heim Brewing Company, of Kansas City, Missouri, and the Frank Fehr Brewery at Louisville, Kentucky. The Boyle Ice Machine Company continued in business until 1884 when the Consolidated Ice Machine Company combined it with the Empire Ice Machine Company of St. Louis. This company was bought by John Featherstone Sons of Chicago. Mr. Boyle continued in business for himself from 1884 on until in 1892 the Pennsylvania Iron Works Company of Philadelphia acquired the Boyle patents which had served to put the compression ammonia machine on a permanent basis.

There followed a number of other ice machines. The first Silas Merchant ammonia compressor machine went into the brewery of A. Ziegele, of Buffalo, New York, in 1877, under the superintendence of John Enright, later of the Arctic Machine Company.

At that time refrigeration was produced by making mountains of ice. It took the engineers some years to persuade brewers and meat packers to rely on direct refrigeration from the pipes without the intervention of ice.

Another name of historical importance in the history of refrigeration in America is that of A. T. Ballantine, of Maine, who first made a rather unsuccessful machine in New York, then a better one in Jersey City, and at last in 1882 a still more efficient one for the brewery of Gerhard Lang, of Buffalo, New York. This machine was later manufactured, in a greatly improved form, of course, by the Case Refrigerating Machine Company, of Buffalo.

Rudolph Schmidt, St. Louis maltster, shortly before 1880 adopted a machine invented by Raoul Pierre Pictet, of Geneva, Switzerland, operating with anhydrous surphurous acid.

In 1879 the Hermann Brewery at New York installed the first machine of the John C. DeLaVergne type which scored an advance over the earlier ammonia compression machines in better sealing of valves and joints and improved lubrication. This machine was introduced widely in American breweries and a big plant was built for the manufacture of it by the DeLa Vergne Company.

The famous machine of Prof. C. P. G. Linde, of Munich, Germany, was first introduced in 1873. Patents were obtained in the United States in 1880 and the machines were manufactured in America by the Fred. W. Wolf Company of Chicago. The Wacker & Birk Brewing & Malting Company, of Chicago, was the first to instal a Linde machine in this country.

The Phoenix plant of Henry Werner, brewer, of Baltimore, Maryland, was the first brewery to instal an Eclipse refrigerating machine manufactured by the Frick Company according to an invention by David Smith.

One of the best known ice machines of later years was manufactured by the York Manufacturing Company, later known as the York Ice Machinery Compan[illegible] York, Pennsylvania. It was originally based on an invention by W. G. Lock, of Sydney, Australia, which was greatly improved by Thomas Shipley, later president of the York company, who ended by designing an entirely new machine.

The Cream City Brewery, of Milwaukee, Wisconsin, installed the first machine built by Weisel & Vilter, later known as the Vilter Manufacturing Company. It was a double acting horizontal refrigerating machine patented in 188[illegible] which became very popular in American breweries.

The Triumph ice m[illegible]chine was designed in 1894 by F. W. Niebling at Cincinnati, Ohio, and built by a company organized for that purpose.

The Knoxville, Tennessee, Brewery in 1887 installed a refrigerating and ice making machine manufactured by the Henry Vogt Machine Company of Louisville, Kentucky. It was of the absorption type and came to be used extensively in breweries.

The Lemp Brewery at St. Louis, in 1878 erected the first machine designed by Theodore Krausch in an American brewery. It was of the ammonia compression type and one of the pioneer refrigerating machines in the American brewing business. For a number of years its manufacture was carried on successfully.

In the laws of the colonial and early national years in America we repeatedly meet with the phrase "the art and mystery of a brewer" or similar expressions.

What gave to the brewer's art the character of a mystery was principally the process of fermentation, and it may be said that it remains today a mystery to most people who are not acquainted with brewery practice or the pertinent sciences. The awe with which man has regarded this natural process finds spontaneous expression in the fact that the animating essence produced by fermentation is identified in language with the essence of human life, both being designated by the term "spirit."

Architecture and Plant Engineering

IN THE earlier part of this chapter and elsewhere on occasion in the course of this history the development of brewery apparatus has been sketched. It was inevitable that as a result of this line of evolution, which may be called equipment engineering, great progress was also made in what may be called plant engineering and in the architecture of breweries.

When the brewery cellars were raised above ground—although they continued to be called cellars—when new apparatus were devised, new arrangements made of equipment, everything planned on a bigger and finally even on a grandiose scale, the construction of the buildings must keep pace with this growth, and when wealth came to reward the brewer's labors, there came also a praiseworthy pride of achievement which found expression in grandeur and beauty of outline of the buildings and elegant outfittings within.

Heavy machinery, huge vats and tanks holding enormous quantities of liquid, called for sturdy construction, iron and steel took the place of frame. Attention to cleanliness required smooth and solid floors, bringing in cement and tile. Fresh air and light, receiving recognition as requisites, tall windows broke the stately walls. Gravity arrangement taking the place of repeated pumping, the buildings grew in height, and the lofty tower brew-house loomed high in the air, decorated with turrets and parapets and pointing up towards the flagpole with the stars and stripes flying at the summit, while aspiring arches received the incoming teams and trucks or sent them forth on their errands. The brewery came to be more than a workshop, more than a factory, more than an office—it became an outstanding ornament to the community, a show-place for the visitor.

Serviceable architecture was not entirely unknown in some of the early ale breweries of the East. Some of them built sturdy vaults under ground which were models of durable construction and stood heavy loads of overhead traffic for many decades. Some were so well built that the owners were reluctant to give them up and kept them in use for years after more modern and efficient plans were available. But in the end they had to give room to the new ways.

The enormous growth of beer production and consumption in the decade 1880-1890 may be taken as marking the starting point of modern brewery architecture in America. The brewers operating at that time not only accommodated themselves to the rapid increase of business of the day but rightly foresaw a future growth of still greater extent and built for further expansion. Many brewing plants grew up in the next few decades that represent little cities in themselves, with

their brew-house, maltings, bottlery, power house, barns and stables and later on, garages, and palatial offices. Even in the smaller places, the brewery, usually a handsome brick structure with white stone trim, was one of the conspicuous buildings of the city and the brewer himself a respected citizen, proud of his calling, tender of the respect of his fellow-townsmen, and happy in this contribution to the architectural display made by his dwelling place.

Greater refinement of efficiency brought constant progress in architecture and plant engineering. The above-ground "cellar" must be insulated to save refrigeration power. Walls were built with insulating spaces, at first air spaces or filled with sawdust, pitch or "mineral wool," later hollow tile and cork or other insulating material. Fireproof construction became general. Wooden tanks even often acquired iron or steel supports and were raised from the ground both to allow better cleaning and to escape the heat of the ground in summer. When mechanical refrigeration first came in, the rooms were cooled by mountains of ice stored in chambers above. Imagine ice chambers twenty feet deep, filled to the top, representing a weight of 1,150 pounds per square foot, let alone the weight of the building. When direct refrigeration without ice became general such massive construction of course vanished. It represents, however, an interesting item in the history of brewery architecture.

A short sketch like the present cannot undertake to go into detail to show the construction of a brewery with all its tanks, containers, machines, apparatus, pipes, engines, transmissions, etc., that must be provided for by the architect and plant engineer. Some rearrangement and greater compactness became possible with the introduction of electric power and individual motor drive for the various machines, an essential step in the brewery where there is so much separate operation of different apparatus with occasional peak loads.

Since the return of beer, new prospects are opening for further mechanical development, and brewery architecture is assuming new forms. Projects for new brewing plants now being erected or planned show modernistic lines and even extreme tower-like structures. The more modern development of plant arrangement, vat and tank construction and placement, clarifying devices and other apparatus for greater compactness will afford brewery architects many opportunities for further exerting their wits in accommodating the new plants and implements and combining them with modern ideas in building construction.

Brewing as a Factor in National Economy

THE latest figures available on the importance of the brewing industry in National economy are those of the decennial census of 1910. By the time the next census came around in 1920 the brewing industry had ceased to function.

According to the census of 1910, which covers the year 1909, the brewing industry ranked sixth among the great industries of the United States in point of capital invested, and seventeenth in point of value of products.

Capital invested in brewing industry	$671,158,000
Wages paid by brewers	$ 41,200,000
Salaries paid by brewers	$ 22,000,000
Number of workers employed in breweries	66,000
Cost of materials used in beer brewing, mostly barley, hops, corn and rice, about	$100,000,000
Capital invested in malting industry	$ 60,000,000
Acres of barley harvested	7,500,000
Hops raised in four principal hop growing states—	
Acres	44,000
Value	$ 8,000,000
Cooperage, invested capital, largely used in making tight cooperage for breweries	$ 50,000,000
Wages paid by coopers	$ 11,000,000
Coal consumption in breweries to produce horsepower	347,726
Value of product of breweries	$374,730,000
This includes Federal taxes amounting to	$ 57,456,411
Taxes and license fees to State and local bodies	*$ 80,000,000*
Places where beer is sold, about	240,000
Employing about 3 adult males each	720,000

Unknown amounts of lumber, tools, bottles, brewing machinery, refrigerating machines, engines, boilers, motors, pipes, bottle caps, feed for horses, etc. Income taxes, transportation charges, rents of the places of sale, their taxes, etc.

These figures were for 1909. In 1914 beer production had increased by 11 per cent. It would be fair to add 10 per cent to the above figures for 1914, and we would then have figures something like these:

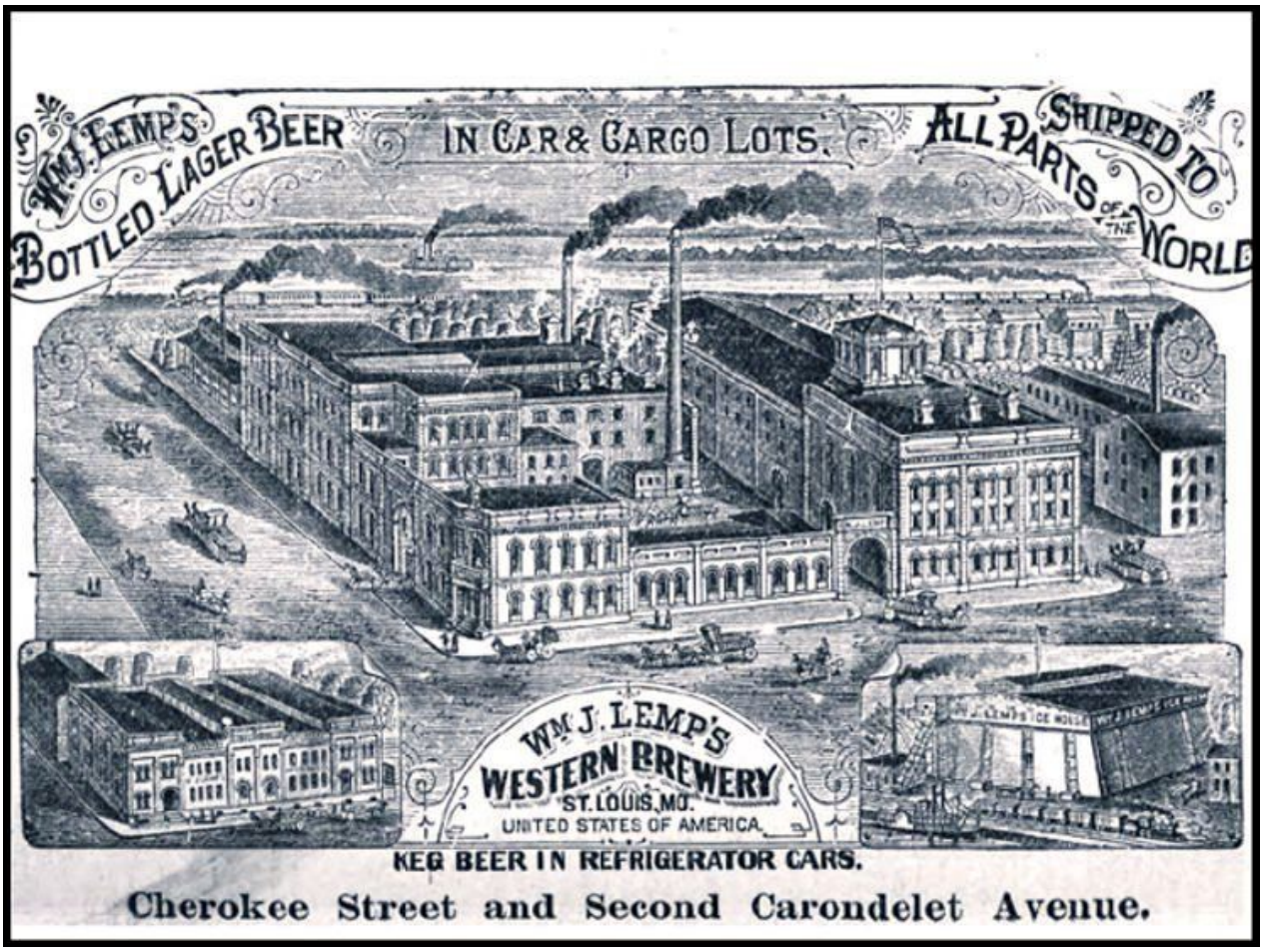
Capital invested in brewing industry proper	$744,985,380
Capital invested in malting industry	66,600,000
Cost of materials used	110,000,000
Capital invested in cooperage	55,000,000

No single scientific and technical advance exerted a farther reach than the introduction of mechanical refrigeration. It liberated the brewer from the distinction between winter beer and summer beer, he was no longer obliged to brew his supply for the summer in winter and to provide adequate storage, mostly underground or in a mountainside, for a huge supply for future use. Perhaps of even greater importance was the ability, given by this improvement, to provide lower temperatures and, above all, to maintain certain temperatures as required at different stages in the brewing process. Coming at the time when the nature of fermentation was beginning to be understood and the relation between temperature and the activity of microorganisms came to be properly apprehended, mechanical refrigeration gave to the brewing industry one of the most powerful helps in its entire history. Reciprocally, the brewing industry helped to develop refrigeration, as is elsewhere told in this book.

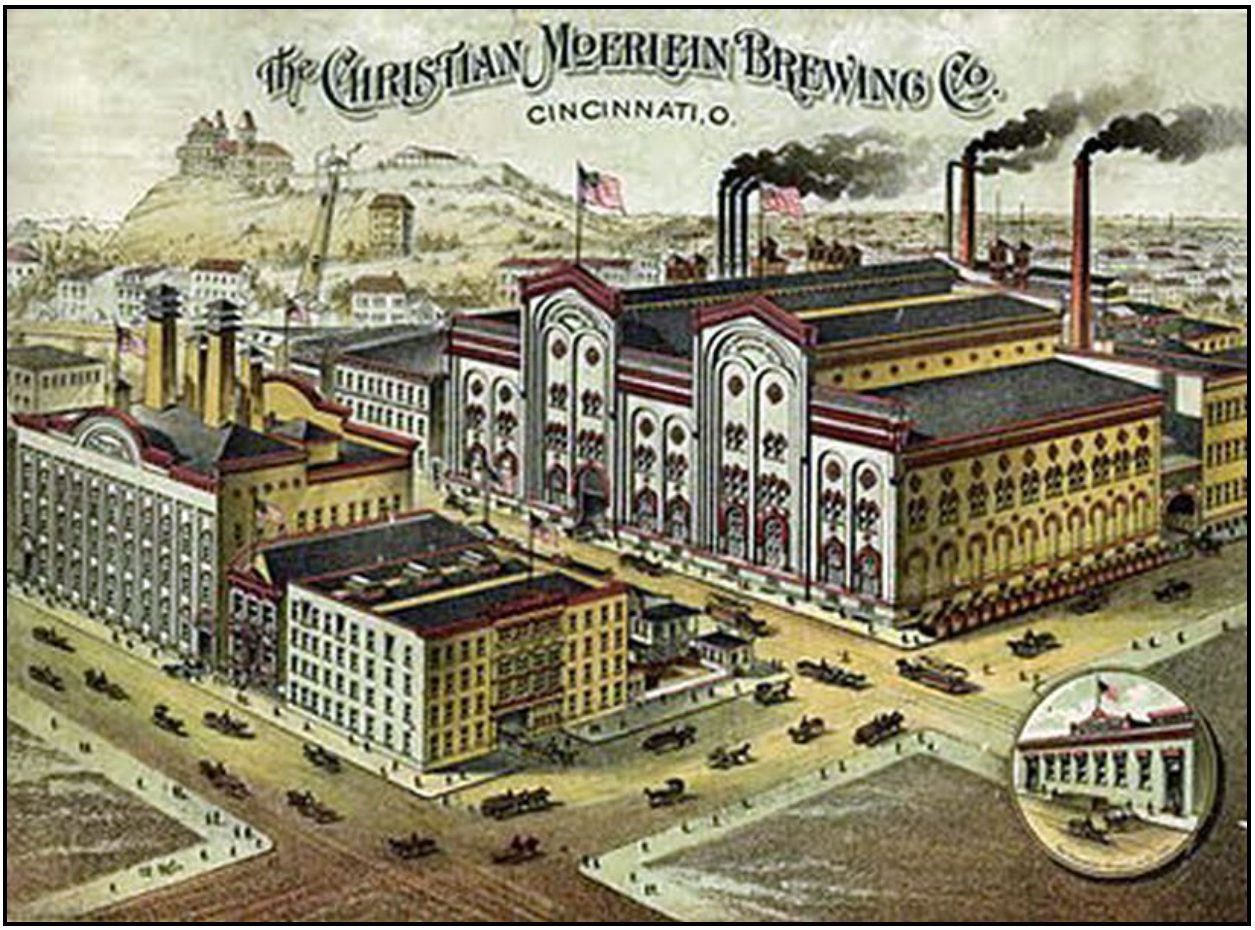
It was in refrigeration that Dr. John E. Siebel made his chief contribution to brewing science and technic, and, it may be said, to industrial science generally. His "Compend of Mechanical Refrigeration" was the most important publication on the subject at the time and has remained a classic ever since.

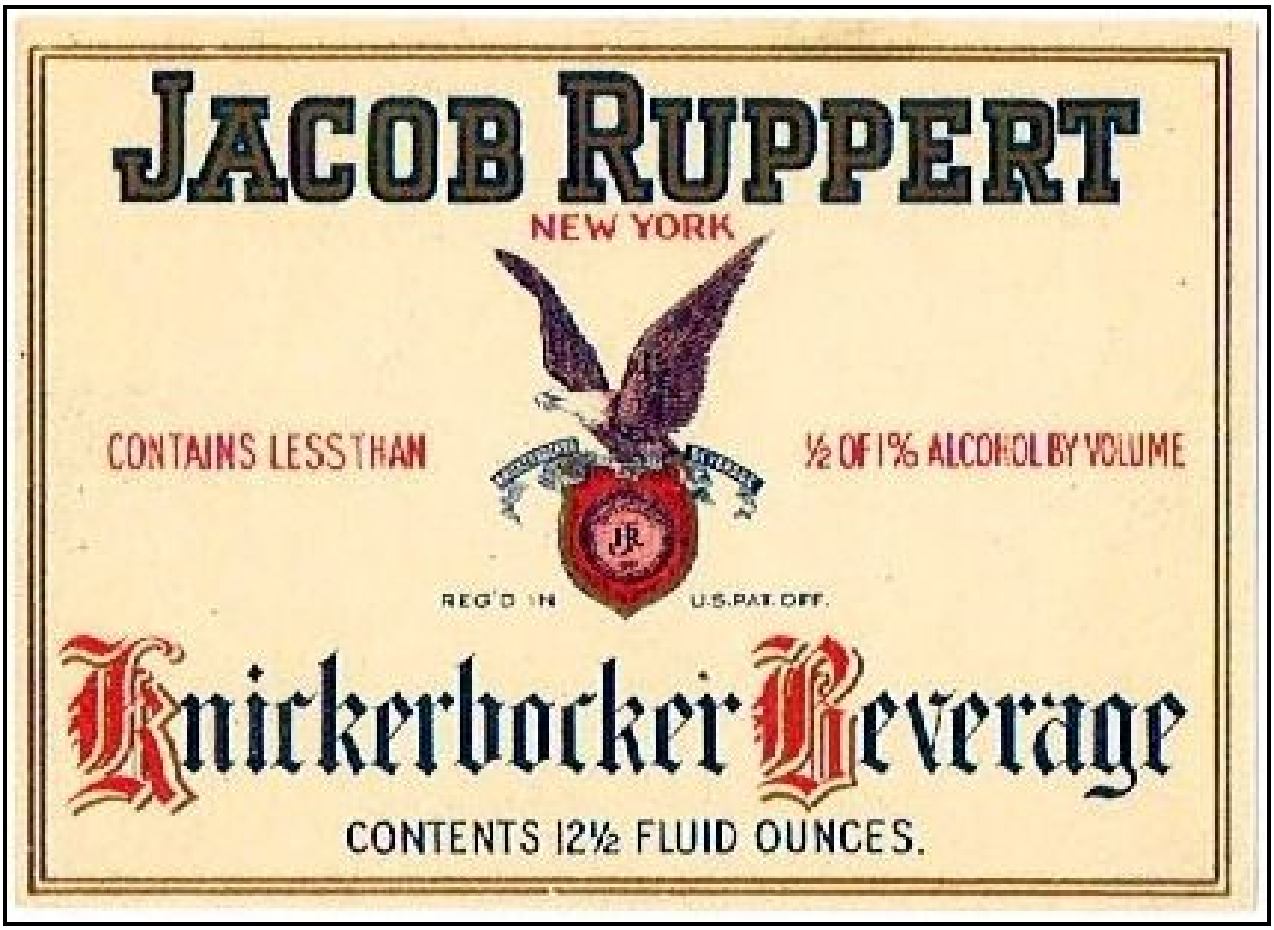
Refrigeration in American Breweries 1860-1920

History of the Brewing Industry



A few of the breweries mentioned in the book extract
HISTORY OF THE BREWING INDUSTRY


The Christian Moerlein Brewing Co.
CINCINNATI, O.


JACOB RUPPERT
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½ OF 1% ALCOHOL BY VOLUME
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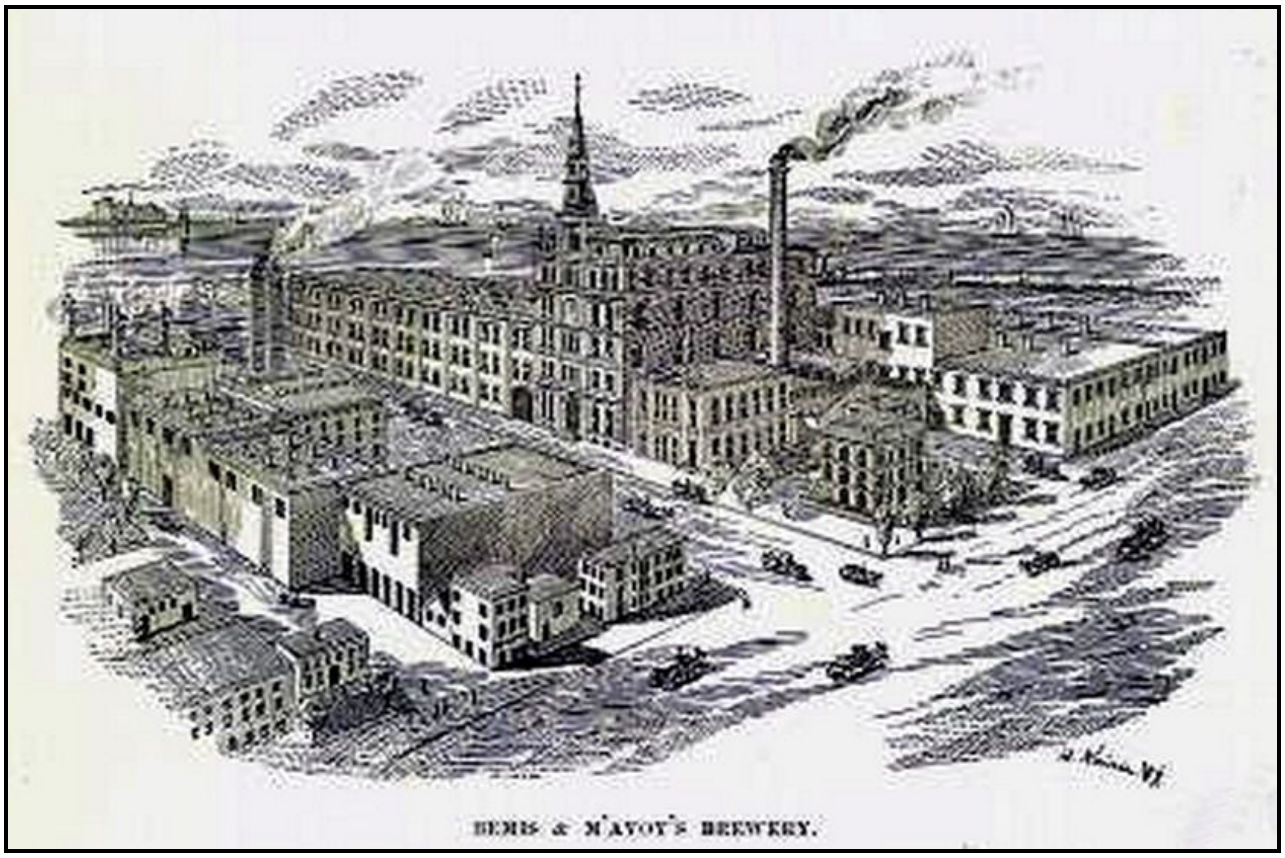
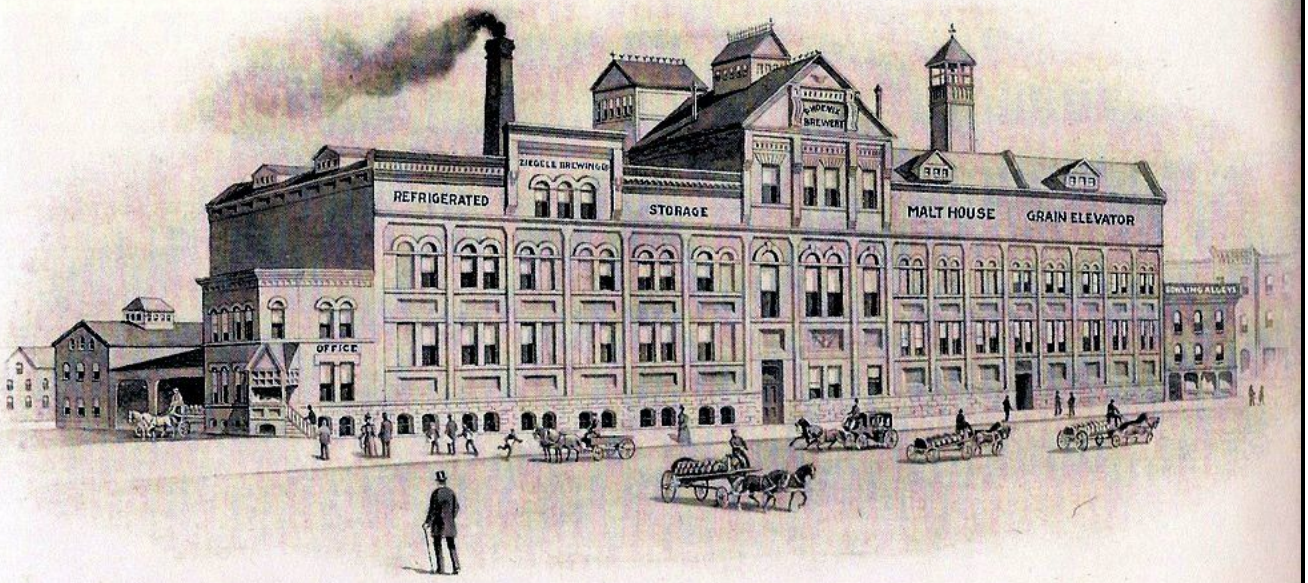
Knickerbocker Beverage
CONTENTS 12½ FLUID OUNCES.

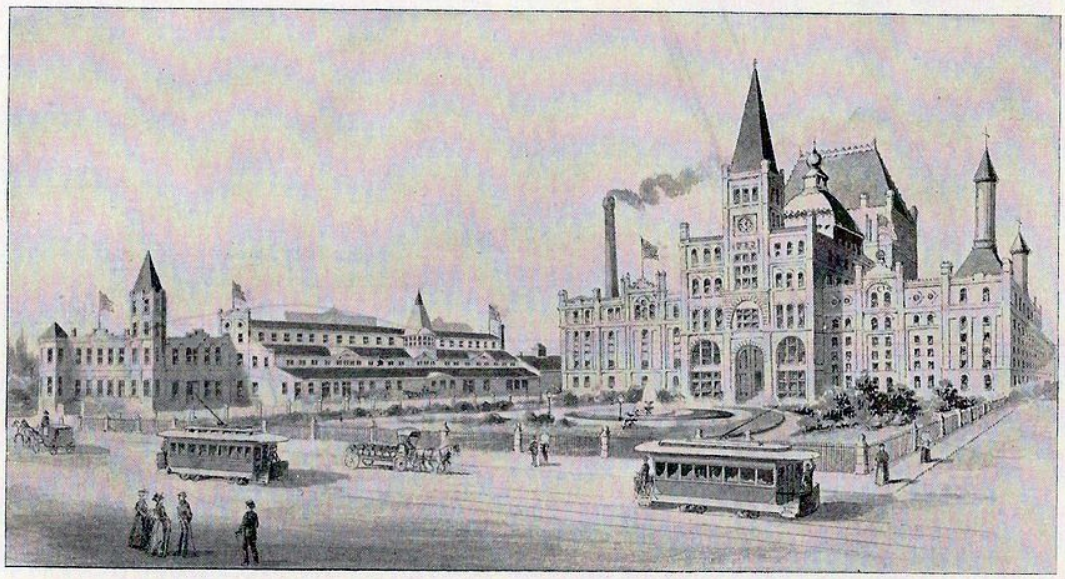


BEERS & M'AVOY'S BREWERY.

Ziegele Brewing Co.



Gerhard Lang Brewery.



President,
EDWIN G. S. MILLER.

Secretary and Treasurer,
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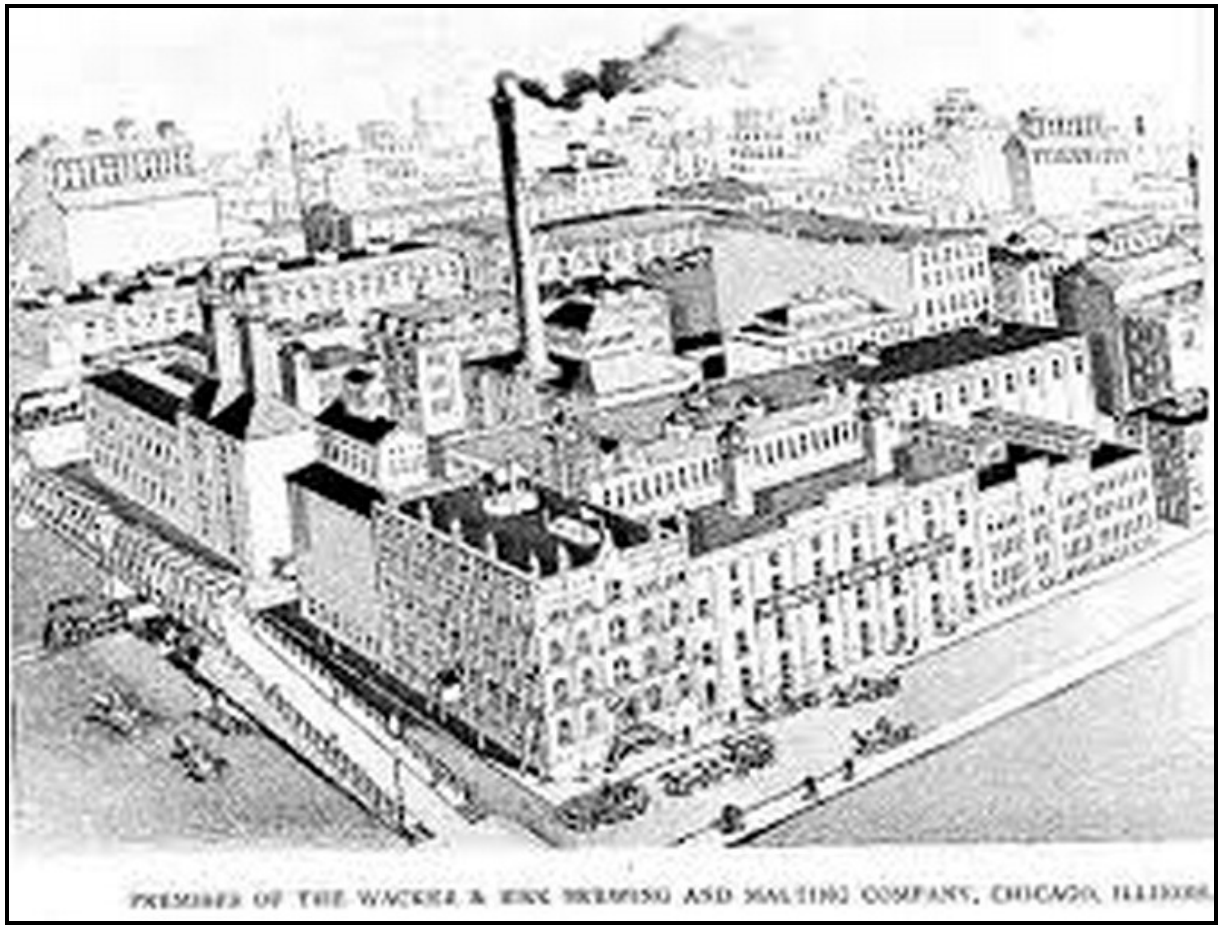
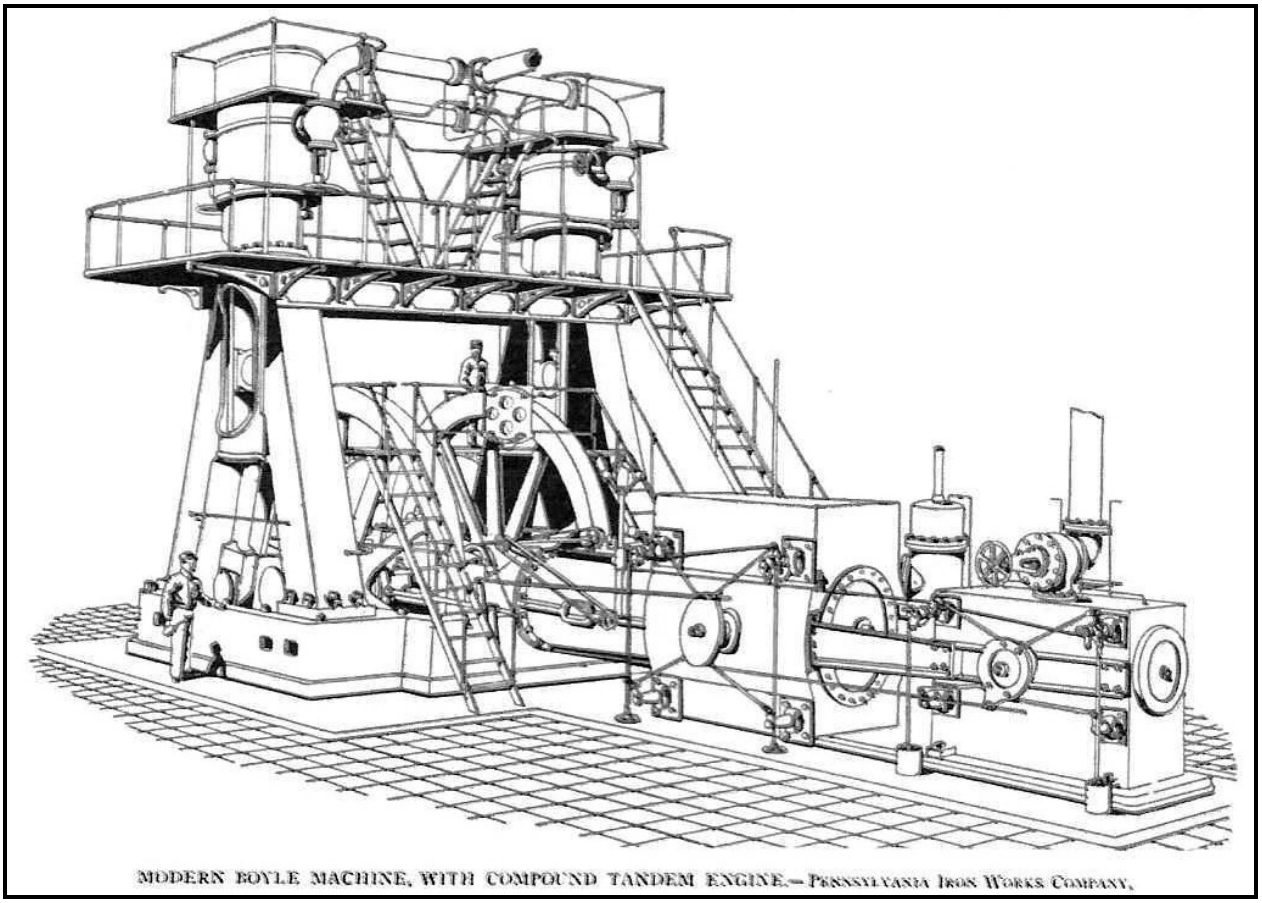


Refrigeration in American Breweries 1860-1920

Introduction of Refrigeration in Brewing



MODERN BOYLE MACHINE, WITH COMPOUND TANDEM ENGINE.—PENNSYLVANIA IRON WORKS COMPANY.

2.3. INTRODUCTION OF REFRIGERATION IN BREWING

2.31. It may seem surprising to find a whole chapter, even if brief, devoted to brewing, as part of the evolution of refrigeration during this period from 1875 to 1914, but there are many reasons for it. In the first place, breweries were very large users of natural ice in many countries, since the middle of the 19th century. There were many drawbacks to this practice, and naturally the breweries were among the first to be interested in possibilities of using artificial cold. The relationship with the preceding chapter is quite close because mechanical refrigeration was first used in breweries to produce ice. Thus, although the breweries represented only a relatively restricted part of the professional life of a country, they absorbed a considerable proportion of the total installed refrigeration capacity, in many countries around 1900 to 1910. This amounted to 70% in Sweden, 60% in Germany and Austria, 50% in Holland, 40% in France and Denmark, and 30% in the United States. Many of the very first refrigerating machines constructed by the great pioneering firms were installed in breweries, around 1860-70, and, oddly enough, brewery refrigeration played a determining rôle in the rational and scientific development of the compression refrigeration system, as we shall see.

2.32. At the beginning of the 19th century, breweries in some countries began to adopt "bottom fermentation", which requires relatively low temperatures for the fermentation of the wort (6 to 8 °C) and for storage of the beer (0 to +4 °C). The standard was set by Germany with its lager; this type of beer was introduced into the United States about 1840. (Great Britain for a long time remained faithful to its "top fermentation" beer.) Without means of controlling the temperature in bottom fermentation it was not possible to make good quality beer except in spring and autumn, in most regions. Thus breweries became large users of natural ice. In Europe, the use of natural ice first began to expand in Austria towards 1820, then in Germany, Switzerland and Alsace-Lorraine. About 1875 in the United States, brewing was the sector of the economy which used most natural ice, many breweries using 20 to 30 000 t/year. The encumbrance of the stock of ice, to get through the summer, was really extravagant. The brewery in Pilsen, the largest in continental Europe, which used natural ice up to 1884, was obliged to operate a system of ponds from which to collect ice in the winter. Thus one can understand why the brewers were only too pleased to welcome artificial refrigeration to free them from such constraint.

How was natural ice used at that time? Recollect that in 1819 Salmon and Warell were granted a British patent for cooling malt in a brewery by blowing cold air over the surface. But the real breakthrough came in 1856, when the French engineer Jean-Louis Baudelot (1797-1881) introduced the wort cooler which bears his name. This is made up of a vertical bank of tubes through which a cold fluid circulates, and over which the wort flows. Iced water could be used in the tubes, and cooling was very rapid. On leaving the "baudelot" the wort is taken to the fer-

mentation vessels, in which at that time the temperature was kept at a correct level by "swimmers" containing natural ice (50 to 60 kg); these floated on the surface. They were much used in Germany and Austria.

When breweries began to use artificial ice, they still used these "swimmers". They also used floating coils of iced water. But it soon became general practice to cool the fermentation vessels by means of fixed immersed systems. Firstly, there were coils of iced water, then systems of tubes sandwiched between two plates. The "baudelot" was still used, with iced water or brine, and later (about 1890) with direct expansion of the refrigerant. (It was only much later that they dared to use direct expansion coils in the fermentation vessels).

It was only in about 1880 that the storage cellars were cooled, and then by ice tanks at the ceiling. In 1882 a German brewery, Aktienbräu at Dortmund, was the first to cool the cellar by brine coils. Much later they were emboldered to put direct expansion coils in the cellar.

2.33. From just before 1860, the large pioneering manufacturers of the period began to install their first refrigerating machines in breweries: in 1859, an ethyl ether compressor of F. Carré in the Velten brewery at Marseille; in 1860, a Harrison ether compressor in the Bendigo brewery near to Melbourne (perhaps there was a machine tested by Harrison in a brewery in 1857); in 1861, a Harrison-Siebe ether compressor in a London brewery; in 1868, a Tellier methyl ether compressor in the Merz brewery in New Orleans; in 1869, a Tellier machine in a Marseille brewery, in 1870, a Carré absorption machine in the Liebmann brewery in Brooklyn, New York.

As early as 1865, Charles Tellier * began to be interested in using refrigeration in brewing; he dealt very clearly with the topic in his book "Ammonia in industry", written in 1866. In 1871, he wrote a leaflet on "Refrigeration applied to the production and storage of beer", but French brewers largely ignored his work. On the contrary, the *International Congress of Brewers,* held in Vienna in 1873, was a resounding success and played a decisive rôle, not only in the development of the use of refrigeration in this industry, but also in a rational consideration of systems of production of cold in general. It was at this congress that Carl von Linde *, then a young professor in Munich, made a convincing story of the advantages of the system using compression of liquefiable gases. The machine using expansion of cold air was defended by Franz Windhausen *, at this congress.

It has already been said that in 1876 and 1877, Linde produced his two types of ammonia compressor. As early as 1877, this type of machine was installed in the Spatenbräu brewery in Munich (where it was used to cool the wort and the fermentation vessels), and in the Dreher brewery in Trieste (cooling also the storage cellars), and then, a little later in the Westminster brewery in London. The winter of 1883-1884 was especially mild in Germany, and the acute shortage of natural ice which resulted threw the brewers into the arms of Linde! In 1881, there were already 750 Linde machines in 445 breweries. The Carlsberg brewery in

Copenhagen installed Linde machines in 1879; their competitor Tuborg, also in Copenhagen, obtained their first machine in 1883 and in 1900 had an installed capacity of 750 000 kcal/h. The Pilsen brewery installed mechanical refrigeration in 1889, to cool wort. It still cooled the storage cellars by natural ice up to 1897, when all cooling was done mechanically. In 1907, they had an installed capacity of more than 3 M kcal/h, and also owned 300 refrigerated wagons. By 1891, most American breweries had changed from natural ice to artificial cooling. In 1904, the total breweries in America had 300 M kcal/h and 5 Mm^3 of cooled cellars. By 1911, the figures were 420 M kcal/h and 7 Mm^3 (the Anheurin Busch brewery, in Saint Louis, alone had 5.2 M kcal/h).

It has already been said that at this time, the English breweries were less interested in refrigeration, because they used top fermentation, but in 1900, there existed many refrigerated warehouses for hops (notably an establishment of 10 000 m^3 in Birmingham).

In 1903, Germany had 1 500 breweries with refrigerating plant (about 70% NH_3, 15% SO_2, 15% CO_2). At the same date, France had less than 100 breweries equipped with refrigeration. In 1915, 93% of the 1 350 breweries in the U.S.A. had refrigeration machinery.

2.34. A first conclusion may be drawn from these two chapters on ice and brewing; very broadly speaking it would be correct to say that the two driving forces for the development of artificial refrigeration, on a world scale around 1875 were: firstly the manufacture of ice in the southern United States, and secondly, brewing in Germany and the northern United States. With the transport of meat by sea, which will now be dealt with, we find the third "big event" of the beginning of this history of refrigeration.