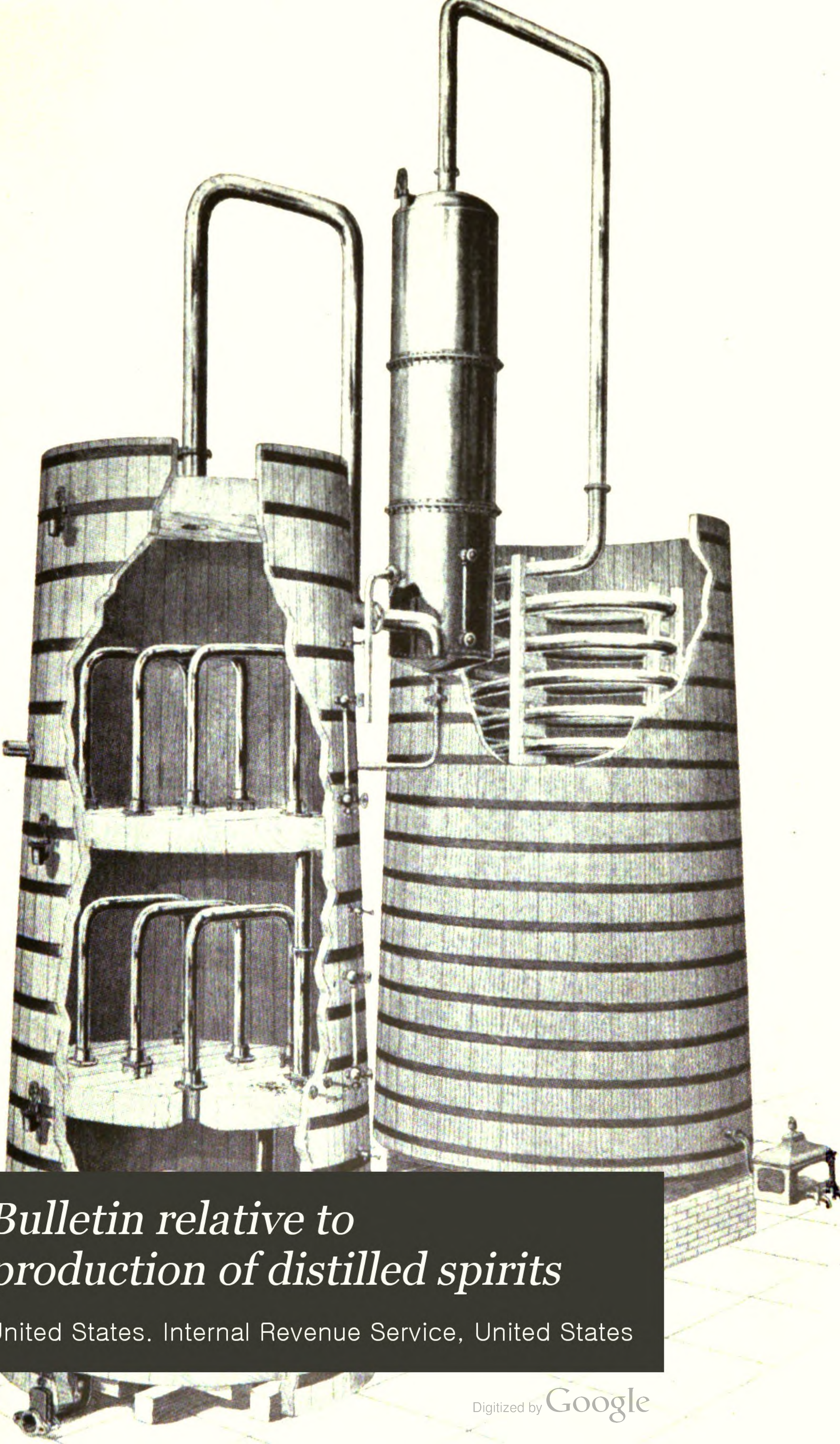

Bulletin relative to production of distilled spirits

United States. Internal Revenue Service, United States

BULLETIN

RELATIVE TO PRODUCTION OF

DISTILLED SPIRITS

PUBLISHED BY THE BUREAU OF
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OFFICE OF COMMISSIONER OF INTERNAL REVENUE

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TREASURY DEPARTMENT,

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TREASURY DEPARTMENT,
OFFICE OF COMMISSIONER OF INTERNAL REVENUE,
Washington, June 1, 1912.

To collectors and all other internal-revenue officers:

The data contained in this bulletin has been compiled and is furnished for the information of all internal-revenue officers, and particularly for the information of those whose duties bring them in touch with the operations of distilleries.

There appears to have been drawn over the operation of distilleries more or less of mystery, when, as a matter of fact, the manufacture of distilled spirits is not a complicated process, but every step is a simple application of well-known laws of chemistry and physics to factors such as material and equipment, which produce, within lines of variation capable of definite ascertainment, very constant results. It is hoped and believed that the information furnished herein, so far as all internal-revenue officers are concerned, removes anything that may be of mystery from the operations of these plants; and it is further expected, and in the future will be required, that every distillery officer shall sufficiently familiarize himself with the simple laws of chemistry and physics involved in the production of spirits so as to understand their application to the materials and the equipment in the plant to which he is assigned.

It is not intended that this bulletin shall constitute a primer or a guide to the production of spirits. An effort has been made to give a general description of the various processes in common use, and an explanation of the reason why certain things are done; and, further than this, that the information herein shall furnish a method by which, from knowing what is done, the officer assigned to a distillery can ascertain whether or not the amount of distilled spirits normally to be expected has resulted therefrom.

Most of the steps are described generally. Where examples or temperatures are given, or processes are discussed, it means that the given examples, temperatures, or processes, are but types which may be and are varied, depending on the equipment or ideas of the particular distiller, the variation, however, being within lines capable of definite ascertainment. The basic principles involved are the same whether the plant is located in one section of the country or another, or whether one process or another is followed.

ROYAL E. CABELL,
Commissioner.

INTRODUCTION.

Chemically, alcohol is the class name for a group of compounds of which ethyl alcohol, or, as commonly called "grain alcohol," is the second member of the series. Wherever the term alcohol is used herein it is used in its commercial meaning; that is, ethyl alcohol (or grain alcohol).

Alcohol is a product resulting from the fermentation of fermentable substances (sugar). There are many materials which contain such substances and in each case they may be used for the production of distilled spirits. Whether they are so used or not depends upon the commercial factor, i. e., the cost of raw material and cost of manufacture.

The material is prepared for fermentation by a process called mashing. After the mash has been placed in the fermenter, fermentation is developed by means of yeast; this may be added by the distiller (as is usually the case) or may be developed from yeasts which drop into the tubs from the air. After the fermentable material has been changed into alcohol the next step is to separate this alcohol in such strength that it can be used for whatever purpose intended. This process is called distillation. The different kinds of stills and steps in the process will be described later.

MATERIALS.

There are four classes of materials used in this country in the production of alcohol. They are, in the order of importance, cereals. molasses, fruit juices, and wood (cellulose).

CEREALS.

Under this head are classed corn, rye, wheat, and barley. In China, Japan, and other eastern countries rice is used. Cereals are composed of starch, water, several per cents of nitrogenous bodies or proteins, a small amount of sugar, a small amount of fat (oil), fiber (outer shells, etc.), and certain other ingredients in small quantities. The moisture content is often the basis on which the price of the cereals is fixed. The starch content in cereals varies inversely as the moisture content. The amount of alcohol which can be produced from these materials depends directly upon the content in starch, as starch is practically the only substance present in cereals capable of being converted into alcohol. The following is a table of the starch content of these cereals:

Cereal.	Average starch content.	Cereal.	Average starch content.
	Per cent.		*Per cent.*
Corn	60-65	Barley	60
Wheat	62	Barley malt (sugar, 16 per cent)	46
Rye	63		

Barley malt is barley which has undergone the process of malting; that is, the kernel has been permitted to sprout, during which process a small per cent of diastase is formed. This diastase has the property of changing starch into sugar, without which no fermentation would occur. Barley malt will contain a lower per cent of starch than the untreated grain, but the loss in starch will be compensated for by the gain in sugar.

MOLASSES.

These are two kinds of molasses used, beet molasses, or the refuse from the manufacture of beet sugar, and cane molasses, the refuse from the manufacture of cane sugar. In both of these materials the fermentable substance is present entirely as sugar and only needs to be diluted with water and yeasted to undergo the process of fermentation. The following are typical analyses of these products:

	Cane molasses.		Beet molasses.
	Louisiana.	Porto Rican.	
	Per cent.	*Per cent.*	*Per cent.*
Water	23.5	24.3	21.83
Sucrose (cane sugar)	26.6	35.8	47.80
Reducing sugars	29.1	18.3	....
Nonsugars	20.8	21.6	30.37

FRUIT JUICES.

Under this heading are included practically all fruit juices, such as from apples, pears, grapes, berries, etc. In each the fermentable matter is present as sugar, it being only necessary to add water and yeast to start fermentation.

WOOD (CELLULOSE).

There is being developed in this country at the present time as a commercial industry the production of ethyl alcohol (or so-called grain alcohol) from cellulose, the source of the cellulose being sawdust and other refuse from lumber mills. In this process the wood fiber is treated with water and sulphurous acid under a heavy pressure, the converters being heated with steam. The pressure produces a very high temperature, a chemical action ensues by which the cellulose is changed into sugar, yeast is then added, and fermentation proceeds as usual. As this process is in an experimental stage, no further mention will be made of it.

NOTE.—This alcohol is not to be confused with wood alcohol, obtained by heating wood in closed retorts, or, as it is called, a destructive distillation. This latter alcohol is poisonous.

MASHING.

By the term "mashing" is understood the preparation of the material to be fermented. This preparation consists, in the case of the fruits and molasses, materials in which all the substances to be fermented are present as sugar, simply in macerating the fruit and adding water, whereby the sugars are dissolved. The molasses is diluted with water so that the per cent of sugar is in proper proportion for the purposes of fermentation.

The material to be acted on is starch. Inasmuch as potatoes are not used extensively in this country as distilling material, no further reference will be made to them. In the case of cereals the grain is first treated, usually cooked with water, so that the starch is gelatinized, then malt is added, the effect of which is that the diastase in the malt first renders the starch soluble in water and then changes the starch to sugar—that is, maltose and dextrin. The maltose is not itself capable of being fermented, but a substance present in the yeast changes it into dextrose, which is fermentable. The dextrin is not fermentable, but sufficient diastase is left in the finished mash to permit action to proceed in the fermenter, through which a portion at least of the dextrin is changed to a fermentable sugar.

Starch is composed of cells, each cell being inclosed in a cell wall. The purpose of heating or "cooking" is to rupture this wall. When the starch is cooked to 212° F., a major portion, but not all, of the cells are broken up, but if the temperature is raised to 309° F. all of the cell walls are supposed to be ruptured.

In the preparation of malt any cereal can be used. It is first soaked in water, then spread in thin layers (in the older process) on floors to allow the germs to sprout. At the end of four or five days, when the sprout is about three-fifths the length of the kernel, the grain is dried at a temperature not to exceed 130° F. The malt is now called "dried" malt and is in the condition as used by distillers in this country. "Green" malt, or the undried malt, is used by brewers. Barley is the grain generally used for malting purposes, because it is considered to have the highest diastatic power of any of the malted cereals. Considerable rye malt is used in the production of an all-rye whisky and a little corn malt is occasionally produced and used. By diastatic power is meant the measure of the activity of the malt in changing starch into sugar.

There are three different methods of mashing:

First, the cooker (see illustration, Fig. I), a large steel vessel very much resembling a boiler, which is used for the mashing of grain (generally corn) and is so constructed that a high pressure of steam can be applied, which in turn produces a high temperature. A certain quantity of water is added to the cooker, about 20 gallons to the bushel (the exact quantity depending upon the ideas of the distiller); this is heated to about 150° F., when the meal is added. The steam is gradually forced into the cooker and the pressure increased until at the height of the process the temperature reached is 309° F. The cooker is provided with rakes by means of which the contents can be kept in motion. This step is called cooking. On the completion of the cooking the pressure is released and a vacuum applied. This causes the mash to cool to the temperature at which the rye is added (if used), about 160° F., then cooled to about 150° F., when the malt is mashed in, usually having first been mashed in a small quantity of water. The temperature of the contents of the cooker is now kept up to what the distiller calls a malting temperature, which is approximately 148° F. It is held at this temperature from 15 to 30 minutes or more. The action which takes place in this step is as follows: The malt contains, as stated, diastase, a substance called by fermentologists an enzyme; this enzyme has two properties, first, that of liquification, or changing the insoluble starch into soluble starch; second, that of saccharification, or converting all the soluble starch into sugar. The best temperature for the former is about 158° F., for the latter 131° to 145° F. A chemical test can be applied to ascertain when a good conversion or saccharification has ensued, this test is applied at some of the better-equipped distilleries. On the completion of the malting process the mashing is then finished and it is only necessary to cool and send it to the fermenter either in its present condition or diluted.

The cooker process is the most efficient, as practically all of the starch cells are broken.

Second, the mash tub. In a majority of distilleries where whisky is produced the tun or key or mash tub (see illustration, fig. 2) is used. This is a large round vessel made of steel or copper, provided with two sets of coils, for heating and cooling purposes, and rakes for stirring. The method of operation is in general as follows: A certain quantity of water is added to the tub for every bushel to be mashed, about 20 gallons to the bushel; the temperature is raised to 120°–150° F., called the "doughing in" temperature; the meal is added, the rakes operated to thoroughly stir. When corn is being used, as soon as the meal is added the temperature is raised to 212° F., held at this point for about 15 minutes; it is then cooled to about

160° F. and the rye mashed in, then further cooled to 150° F. and the malt added. When rye is used the mash is not cooked over 160° F.

The yields, obtained from the use of the open mash tub plan distillery are not as high as from the use of the cooker plan, because in the former all of the starch cells are not broken up in the mashing process, and therefore some escape the action of the diastase in the malt, whereas in the cooker the high temperature—309° F.—is supposed to rupture practically every one of the starch cells.

Third, the small tub or old sour mash process. The details vary, but the following is the general process: A certain quantity of hot slop, about 20 gallons to the bushel, is placed in small tubs (capacity about 50 gallons, sometimes more); the meal is then added and the entire mass thoroughly stirred with the mash sticks. This is allowed to stand overnight, in the morning it is broken up by means of mash sticks; the malt and rye is then added, in some places without heating the mash, in others after heating to about 160° F., allowed to stand for some time and then sent to the fermenters. This process does not give as good results in mashing as the open mash tub, because a smaller number of the starch cells are acted on in the process, and a smaller yield is obtained.

YEASTING.

Although for the purposes of this discussion yeasting is treated as a separate stage in the process, it should be understood that the preparation of yeast is in reality fermentation; the yeast tub is just as much a fermenter as the beer tub. For every bushel of grain which is used in a yeast tub a proportionate quantity of alcohol is produced as a product of the growth of the yeast.

After the mash has been prepared it is ready for yeasting. Yeast is a vegetable organism, called by botanists a unicellular structure, because it consists of one cell, which cell increases or propagates by budding or sporing. For yeast growth three things are necessary: A supply of fermentable material, a supply of yeast food in the form of nitrogenous bodies and certain mineral substances, and a supply of oxygen (air).

There is present in the atmosphere, particularly of distilleries, other types of yeast than those desired for fermentation called "wild" yeast, and also present various molds and bacteria; all of these are "undesirables" because they consume the fermentable material either with a less production of alcohol than a good yeast or produce other bodies, as acetic acid, etc. Certain of the bacteria in turn consume the alcohol produced by the yeast. The purer the race of yeast the better the yield of alcohol.

There are three methods of yeasting in vogue: First, to allow the tub to be yeasted by the yeast organisms which fall into it from the air or are remaining in the fermenters; second, yeasting back, or the use of "barm"; third, the preparation of a yeast mash in a quantity representing from 2 to 4 per cent of the grain bill.

First method, no yeasting used.—At a very few small distilleries no added yeast (neither mash nor barm) is used. The mash is prepared and placed in fermenters, the distiller leaving the tubs to nature, and as yeast cells are present nearly everywhere, some cells drop into the mash and fermentation begins. As other organisms also develop, this fermentation is a poor one and the lowest yields are obtained from this process. In the early days of the industry this was the general method employed.

Second method, yeasting back, or the old sour-mash process.—After the mash has been prepared in the small tubs, as before described, and emptied into the fermenters, the new mash is yeasted by taking from a tub set the day before and presumably in active fermentation the "barm"; that is, the top is skimmed off, containing a large number of yeast cells, which will immediately begin to grow in the new mash.

After this tub has been fermenting 24 hours, the "barm" is skimmed off of it for use in the next tub, and so on. In this method the yeast is less vigorous than in the third method, hereinafter described, because in addition to the race of yeast desired there is an abundance of other types of yeasts and various bacteria which interfere and tend to cause a low yield by a development of other substances in place of alcohol. The longer the process of yeasting back continues the less vigorous the barm becomes, as far as the true yeast is concerned, though it becomes very rich in the varieties not desired. Finally the tubs will become so foul that a fresh start has to be made by obtaining a quantity of yeast from other sources. In a distillery operating strictly on this plan there would be no yeast tub on the premises.

Third method, yeast mash.—It is not the purpose to state how a yeast mash may be developed from one cell of yeast under such aseptic conditions that the yeast mash which is added to the fermenter is composed almost entirely of cells propagated from the single cell; in many houses this is done.

The average system of making a yeast mash is somewhat along the following lines: A yeast mash is prepared of malt, or malt and rye and hop water; this will have a gravity of 20 per cent or more; it is stocked with a good yeast and allowed to ferment. At the proper time, after active fermentation has ensued, it is drawn off into jugs of one-half gallon or more capacity. These jugs are used as stock and will keep a month or more before the yeast contained therein will degenerate. Each day a "dona" is prepared by mashing barley malt and adding a little hop water; this is cooled to the proper temperature and set with one of the jugs; it is then allowed to ferment overnight or even 24 hours. A yeast mash in the meantime is prepared by mashing one-half barley malt, one-half rye, cooled and set with the dona. This mash is allowed to ferment overnight or longer and is then ready to add to the fermenter. The grain represented in the yeast mash is from 2 to 4 per cent of the total grain bill for the day (and as all of this grain produces alcohol it should be included in the grain account). In the preparation of the yeast mash at some distilleries another step is taken: After the mashing of the rye and malt the mash is held at about 124° F. from 18 to 24 hours to sour; that is, to permit lactic acid bacteria to develop. This bacteria is not injurious to the yeast, but is an enemy of certain bacteria which are harmful to the yeast. After the souring the mash is either cooled and pitched with the dona or heated to kill the lactic acid bacteria, and then cooled and set (this is called "wine sour").

The three steps—jug to dona, dona to yeast mash, yeast mash to fermenter—are taken in order to obtain a healthy and vigorous growth of yeast and keep it in this condition.

FERMENTATION.

Fermentation is the process by which a fermentable substance (sugar) is converted, by growing yeast cells, into alcohol and carbonic acid gas. (Certain molds also produce alcohol as a product of their growth, but these are not used commercially in this country for the production of alcohol.) Fermentation does not ensue unless there is yeast growth—that is, unless the cells multiply. If fermentation is produced in a tub it means that yeast is present whether added by the distiller or by nature. As stated before, for this growth three things are necessary: A supply of fermentable material, a supply of nitrogenous bodies, and a supply of air. If these are present and the mash is at the proper temperature the yeast will grow, decomposing the fermentable material into alcohol and carbonic acid gas according to the following reaction:

$$C_6H_{12}O_6 = 2C_2H_6O + 2CO_2$$

(Sugar, dextrose.) (Alcohol.) (Carbonic-acid gas.)

The carbonic-acid gas passes off into the air, while the alcohol remains mixed with the water and other materials, the mixture being generally designated as "beer," and the alcohol can be separated therefrom by distillation.

The course and extent of the fermentation can be studied and definitely determined by means of an instrument generally designated as a "stem" (saccharometer), which measures the amount of solids held in solution. As the sugar is consumed the amount of solids in the solution of course decreases and the saccharometer reading being taken from time to time this decrease is indicated on the stem and can be accurately read.

Yeast during growth produces heat; therefore in any fermenter working satisfactorily a rise in temperature is noted. This rise in temperature must not go too far, however, or the heat developed will kill the yeast. A temperature of 100° F. would probably either kill or seriously injure the ordinary yeast used in a grain distillery. In the southern houses, where molasses is used, the yeast, however, is cultivated to stand a higher temperature, 104° F. at the height of fermentation being the rule.

There are four legal periods of fermentation in the United States—that is, the statutes recognize four different periods during which a tub can be filled but once.

First. The sweet-mash process, in which 72 hours is the maximum time, and 45 gallons of beer must represent not less than 1 bushel of grain.

Second. The sour-mash process, in which 96 hours is the maximum period and in which 60 gallons of beer must represent not less than 1 bushel of grain.

Third. The filtration-aeration process, in which 24 hours is the maximum period, and 70 gallons represents not less than 1 bushel of grain. (This is a process in which yeast for bakers is the main product, and alcohol more or less a by-product.)

Fourth. The rum period, in which 144 hours is the maximum period, and 7 gallons of beer represents 1 gallon of molasses.

NOTE.—A distiller who desires to use molasses and make alcohol, and not rum, can have his distillery surveyed on a sweet mash period of fermentation and use 7 gallons of beer to represent 1 gallon of molasses. The advantage in the shorter period lies in the opportunity afforded for operating with fewer fermenters.

It is immaterial which period of fermentation, or what system of yeasting, is used, the process of fermentation is the same.

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DISTILLATION.

Distillation, for the purpose of this bulletin, is the process by which alcohol is separated from the liquid in which it has been produced by fermentation. The liquid while still containing the alcohol and other ingredients is usually called "beer." The distillation of alcohol is merely a mechanical process of purification, as no chemical change takes place. The distillates have the same chemical composition as the original substance. The distillation is only the mechanical separation of the secondary ingredients (taken together after separation, generally called "spent beer" or "slop"), from the principal ingredient—the alcohol.

The process, briefly, is as follows: The beer being subjected to boiling temperature, the alcohol and a part of the water are vaporized and are driven off through the still, leaving behind all solid matter and a part of the water. The vapors are cooled by means of cold water applied in various ways to the pipes or apparatus through which they are passed, and are condensed to the liquid state, the resulting product being a solution of alcohol and water, the strength of which depends upon the type of still used and the method employed. If after the first distillation, the solution is not of sufficient alcoholic strength, the percentage of alcohol can be increased by subjecting it to another distillation.

Distillation can be divided into two classes, the class depending upon the liquid to be distilled—that is, one class for the fermented liquid, or beer, the second class for the "singlings," or a mixture of alcohol and water. The purpose of the second distillation is either to raise the proof or to increase the purity of the distillate. In both of these cases there are several types of stills used.

Distillation of beer.—All of the stills used for the distillation of the fermented liquid can be classed as simple stills—that is, they produce an alcoholic distillate which has not been freed from the products of fermentation called fusel oil. There are three different types of stills in this class: The pot still, the charge chambered beer still, and the continuous beer still.

The pot still (see illustration, fig. 3) is the type of still usually seen in a small house. It consists of a round or oval shaped vessel in which the beer is placed; upon the top of this is a boiling head, the purpose of which is to give sufficient space to prevent the beer boiling over; this is connected to the condenser by means of the goose or vapor pipe. The condenser on this type of still is generally a worm surrounded by cooling water. The vapors are here condensed to the liquid state. The source of heat in this still is either live steam or fire. The advantage of live steam is that during the course of heating the beer is thoroughly agitated; with the application of fire heat the disadvantage arises that unless some system of stirring is used the beer "bumps" considerably in the boiling process and considerably more boiling space would have to be allowed for than in the use of live steam.

Charge chambered beer still (see illustration, fig. 4).—This still consists of from two to four chambers, and is so arranged that each chamber is a unit in itself. The beer is placed in the top chamber and after one distillation the contents of the top chamber is lowered into the chamber below, and a quantity of new beer dropped in the upper chamber. The method of heating is by live steam entering in the lowest chamber. The vapors, consisting of a mixture of alcohol and water, pass from the lower chamber through a vapor pipe to the bottom of the chamber above, these vapors in turn heating the beer in this chamber, boiling the spirit out of it. If there is a third and fourth chamber the same process is repeated. From the upper chamber the vapors pass through a vapor pipe into a doubler, which is a large cylindrical copper vessel, into the bottom of which is placed, at the end of each charge, the heads and tails of the previous distillation. A vapor pipe from the upper chamber enters at the bottom of this doubler, the hot vapors, boiling the heads and tails, pass up the doubler into another vapor pipe, and hence into the condenser. The time consumed in the distillation of one charge is determined by the spirit runner judging by the proof of the distillate. When he is satisfied that all of the alcohol has been boiled out of the beer in the lowest chamber the spent beer is emptied into the spent-beer tank and in turn the contents of each chamber is emptied into the chamber below; steam is again turned into the lower compartment and the process continued. It takes approximately 30 minutes to run a charge and there are as many charges as are necessary to distill the beer for that day. These are the stills invariably used at the larger houses in the distillation of *rye* beers. The distillate of each charge of this still varies in proof, beginning at a low proof, say 40 or more, running up to a maximum of 140 and then down to approximately 10. According to the ideas of the distiller, this distillate is cut off into heads, middle run, and tails. The strongest part of the distillation being classed as middle run. All the middle runs of the various charges distilled during the day are mixed together and called singlings or high wines. The heads and tails of each charge are, as a rule, mixed together and at the end of the distillation of each charge are placed in the doubler of the beer still where they are subjected to a further boiling, and thus the alcohol contained therein is saved and the product called the middle run is kept free of the undesirable substances present in these heads and tails. At certain houses this separation may not be practiced, but all the different distillates mixed together, the disadvantage being that a lower proof is obtained.

Continuous beer still.—The continuous beer still (see illustration, fig. 5) is composed of three parts—the still proper, the beer heater, and the condenser. The still proper is a tall copper cylinder, depending upon the capacity, the diameter varying from 12 to 60 inches. Inside of the still are a series of plates, in some as few as six, the better stills having from 12 to 24.

The operation of this still is as follows: The beer is pumped up through the beer heater, where it receives an initial heating by being brought in contact with the tubes through which the alcoholic vapor is passing on its way to the condenser from the still. The beer heater is of such capacity that the beer is pumped to the second chamber from the top of the still at nearly the boiling point of the liquid; it flows across this plate until it reaches a down pipe which projects about one inch or more above the surface of the plate. The beer passes into the down pipe and flows across the next plate until it reaches the down pipe of the next chamber, and so on until the bottom of the still is reached. Live steam is used, entering the still at the bottom. Each of the plates is perforated with a number of holes. The pressure of the steam is not only sufficient to force its way up through the holes but to prevent the beer from dropping through them. The beer leaves the chamber by means of the down pipe, it being so arranged that the beer covers each plate to the depth of an inch or more; in this way the beer with all its alcohol enters the second chamber and by the time it reaches the last chamber all of the alcohol has been vaporized by the steam. The vapors pass out of the top of the still through the beer heater, where a preliminary condensation takes place. Some low proof spirits being condensed, these are returned to the still by means of a low wine pipe, the uncondensed vapor spass through the beer heater into the condenser, where they are condensed to liquid. The advantage of this still is that when once set it produces a spirit of almost the same proof from the beginning to the end of the run, and, therefore, no heads and tails have to be cut out of the spirit, it being of uniform quality. This is the type of still used in nearly all of the larger houses mashing corn.

As distillation is a simple process consisting in driving off the alcohol the yield of spirit to be expected from a beer can be ascertained by determining the per cent of alcohol in the beer, multiplying by the gallons of beer, and substracting a certain amount for alcohol lost in the slop.

Redistillation.—Redistillation is made for one of three purposes. In the small house where an inferior still is used and a proof less than 100° is obtained to raise the alcoholic strength to proof. In whisky houses in order to cleanse the first distillation, as it is the idea of some that double-distilled whisky is superior to single-distilled whisky. In the production of alcohol for commercial purposes it is desired to obtain a spirit of 188° to 190° proof or over, also to rid the spirit of the fusel oils which are a product of fermentation and which come over with the distillate of the beer still.

The stills used in the first two cases are generally of the pot-still type identical with those described in the first beer distillation, except that the heating is done with fire or a closed steam coil. As there are no solids present in the distillate it is not necessary to stir the contents of this still. This distillate would be cut off into heads, middle run, and tails, according to the ideas of the individual distiller. The middle run would be the best spirit produced and the heads and tails classed as low wines would be redistilled with the next day's beer in the beer still. In this way the loss of alcohol due to redistillation is reduced to a minimum.

The still in use for the production of alcohol (see illustration, fig. 6) consists of four distinct parts, the kettle, the column (which sets directly over the kettle or is connected with the kettle by means of a short goose neck) a goose, or in some places a tubular separator, and a condenser. The kettle as the name implies is simply a large container or boiler in which is placed the singlings to be distilled. The column consists of a series of plates numbering from 18 to in some types 40; these plates are perforated with boiling caps which are so arranged that as the vapors come up from the lower chamber they are forced to pass through the liquid on the plate, thus boiling it. The vapors then continue up through the next boiling cap into the next upper chamber; the level of the liquid on the plates is maintained by a series of down pipes similar to those in a continuous beer still. In the course of this distillation the plates condense out of the vapors the water and the fusel oil. When the vapors reach the top of the still they pass into the goose which is composed of a series of pipes arranged very much like a radiator, surrounded by water at approximately the temperature of boiling alcohol, the object being to further purify the distillate. The vapors pass through the goose into the condenser where they are condensed to a liquid state. The distillate from this still is not a uniform product but varies in strength and purity, the best spirit coming over in the middle run and varying from 60 to 75 per cent of the total contents of the kettle. The different parts or fractions of the run are classed in the order of distillation as low wines, heads, middle run, tails, low wines, and fusel oil. As a rule the fusel oil is not run off with each charge, but is distilled after the second or third charge of the kettle. The kettle is heated by steam coils, it taking about 30 hours to distill one charge.

CHARCOAL FILTERS.

At one time it was a general practice to filter the distillate of the beer still through charcoal filters, or as they are called "rectifiers." This practice is still followed at several distilleries. Sometimes the singlings are leached (as it is called) and bonded without redistillation; at other houses they are redistilled.

At houses where high-proof spirits are produced it is the general custom to leach the singlings through these filters, under a heavy pressure, before the product is redistilled in the kettle.

CONTROL.

Nearly all of the larger distilleries keep a scientific control of their operation and production. From the earliest days the Federal statutes made provision for scientific control by the Government, and these statutes, which internal-revenue officers have not availed themselves of generally in the past, will be utilized fully from this time on. The possibility of scientific control lies in the fact that the amount of alcohol capable of being produced depends absolutely on the per cent of sugar in the mash, and this amount of sugar can, by use of the saccharometer, be accurately measured and the amount of alcohol developed by fermentation definitely ascertained; and by intelligent observation, by a competent officer, of the processes followed in any plant, the amount lost in fermentation and distillation closely estimated, and the production that should be recorded as entered into the cistern room closely calculated.

In the use of cereals the starch is converted into sugar. Theoretically 90 pounds of starch produce 100 pounds of sugar (dextrose), but in actual practice it takes from 92 to 94 pounds of starch to produce this amount. It has been practically demonstrated that a given amount of starch will produce a definite amount of sugar (within certain narrow limits). The sugar is converted into alcohol and carbonic acid gas, theoretically 100 pounds of sugar yielding 51.1 pounds of alcohol. In actual process the yield is less, but can be accurately computed within certain limits. Therefore, given a certain amount of sugar, a definite yield of alcohol can be expected.

As sugar is soluble in water, the amount of sugar present in beer can be accurately and easily determined by means of an instrument called a saccharometer. This saccharometer, or stem, as it is called, has a graduated scale from 0 up, representing per cents of sugar. It is so constructed that on being carefully lowered into a solution of sugar it will indicate directly the per cent of sugar contained therein. The instrument is standardized at a certain temperature, 60° F., the internal-revenue standard, or sometimes 63.50° F., and if the temperature of the liquid tested is higher a correction should be added to the apparent reading; if lower, a correction subtracted.

During the course of the fermentation the sugar is destroyed, yielding alcohol and gas. As soon as any sugar is destroyed it is indicated by the stem reading less than it did on the first test. As the alcohol has a lower specific gravity than water, its presence in the liquid will cause the stem to show a lower percentage of sugar than is actually present; this error will be more or less constant in beers of the same density and is compensated for in the method of checking to be used.

It can be seen from the foregoing that crowding of a mash can be immediately detected by a storekeeper on taking the gravity when the fermenter is filled.

Grain does not contain more than a certain maximum of starch, and only a definite amount of sugar can be obtained therefrom; therefore it has been an easy matter to arrive at a maximum gravity which could be obtained from a mash of a certain strength. These maximums are as follows:

Corn mash.	Maximum gravity.
60-gallon beer	[a] 8.5
55-gallon beer	[a] 9.6
50-gallon beer	[a] 10.8
45-gallon beer	[a] 12.0
40-gallon beer	[a] 13.1

[a] Corrected for temperature.

At present maximums can not be given for other formulæ other than to state that they will in no case exceed the figures given above.

After a tub has been set and the gravity taken the course of the fermentation can be measured by the stem, as the sugar is consumed, developing alcohol and gas. The loss in sugar will be observed by the stem indicating a less per cent of sugar than when the tub was filled; for instance, the following is an abstract of Form 88 of one tub for four days, with a 60 gallon beer being used:

	Filling.	Second day.	Third day.	Fourth day.	Empty.
Temperature	64	66	72	74	68
Gravity	7.8	7.0	3.0	0.7	0.1

Adding the correction for temperature for this we have a filling gravity of 7.9 per cent sugar and emptying gravity of 0.3; this shows a loss in gravity of 7.6; this loss is also called "attenuation" of the beer. By an intelligent use of this determination the yield which a given distillery should produce can be known within certain limits, as the loss in distillation is a constant one for good apparatus, and if poor or defective apparatus or inefficient management exists at a plant, special reports relative thereto should be made regularly by the distillery officers.

Factors have been determined which represent the amount of proof spirit in gallons which should be produced from 1 per cent of "attenuation," or loss of gravity. These factors are as follows:

Gallons of mash per bushel of grain used	40	45	50	55	60
Production in proof gallons per per cent of attenuation in fermentation	0.41	0.46	0.51	0.56	0.60

The calculation of the yield will be made as follows: Taking the figures given in the example of fermentation cited above, there was an attenuation of 7.6 in a 60 gallon beer. One per cent of attenuation should produce 0.6 of a gallon of proof spirits; this distillation would therefore be expected to produce for every bushel of grain mashed $7.6 \times .6 = 4.560$ gallons of proof spirits.

These factors have been obtained from practical experience and are a "mean" for the average house of this class. Well-equipped and well-managed plants will exceed these figures.

Distillery officers are expected to exercise the utmost care in taking and recording their saccharometer readings to see they are entirely correct. If a distillery officer finds his gravity exceeds the maximum he will know that the mash is crowded, and he will immediately report the fact to the collector in writing and make every effort to find out when and how the crowding was accomplished. If the gravity constantly approaches the maximum the distillery officer will take note of the kinds and character of material that is being used and ascertain whether exceptionally high-grade material is being used, in which event the production should exceed the production indicated by the tables herein. Distillery officers are expected to closely watch the daily production of a distillery and if on any day the production falls below 90 per cent of the calculated production, figured on the basis of the tables herein, immediate written report of this fact shall be made by such distillery officer to his collector, reciting all of the facts relative thereto in detail. The collector will report these facts to the revenue agent and to this office, and both the collector and revenue agent are expected to immediately institute the necessary investigation to ascertain the cause of the low production.

The result of examination of records at every distillery throughout the country would indicate that at no distillery possessing normal equipment and normally efficient management should the yield fall below 90 per cent of the yield indicated in the table above. Whenever a distillery officer has to report a lesser yield than this, and such yield is due to inefficient management, unsanitary conditions at the distillery, poor or defective equipment, the distillery officer will report in detail relative thereto. Every distiller should bear in mind that under the law the tax is due on all of the yield produced by fermentation irrespective of whether or not such alcohol is saved to the distiller by his distilling it and running it into the cistern room.

Whenever an examining officer visits a distillery he is expected to test the beer in each fermenter and compare his results with those of the distillery officer. If the results indicate that the proper gravity has not been taken and recorded by the distillery officer in charge, the examining officer will make immediate report to the revenue agent in charge, using his judgment as to whether such report should be by writing or by telegraph, and the instructions issued by this office with respect to keeping of Form 88 should then promptly be followed by the revenue agent, and prompt reports relative thereto should be forwarded direct to the bureau.

Heavy responsibilities devolve on distillery officers and they must be as thoroughly trusted as any class of Government employees. In no other position in the Government is there greater necessity for alertness, competency, and intelligent action at all times. The Bureau of Internal Revenue believes that it is to be congratulated on the internal-revenue officers as a whole. It is the constant effort of the bureau to further raise the standard of these officers by discovering and visiting with severe punishment the few unworthy persons who from time to time find their way into the service.

In addition to the check which can be exercised by the officers at a distillery, the conditions of the mash, whether crowded or otherwise, and the yield of spirits can be accurately determined by chemical analysis. Where chemical analysis is to be made either by request of the bureau or by request of the collector or field officers, after the tub from which the sample is to be taken has been plunged and the gravity determined, a quart sample is to be taken and treated in accordance with instructions sent out from the laboratory, and forwarded in accordance with the same instructions to the "Chemical Laboratory, Bureau of Internal Revenue, Washington," where the sample is carefully filtered and the solids, largely sugar, determined by analysis. If the reading of the stem has been accurately made, the gravity as determined by the reading will not differ from that shown by chemical analysis more than two or three tenths of 1 per cent.

If a sample is taken during the course of a fermentation, or at the end, and the per cent of alcohol and also the per cent of solids determined, the original gravity can be calculated as per the following specimen analysis:

A sample of a 60-gallon beer taken on the last day of fermentation gave the following results:

	Volume.	Weight.
Percentage of alcohol	3.38	2.705
Percentage of solids	....	2.13

As approximately 2 parts by weight of sugar produce 1 part by weight of alcohol, multiply the alcohol by weight by 2 to obtain weight of sugar fermented and add the solids left in the beer unacted upon. Where beer has been fermenting for four days about 0.6 of 1 per cent of the original gravity has been lost by evaporation, etc. The figures on the above example are:

2.705×2=5.410=sugar fermented into alcohol.
2.13 =solids not fermented.

7.540=calculated original gravity.

The gravity figures obtained by the storekeeper on filling were 7.7 at 77° F., correcting for temperature the per cent of solids in solution when the fermenters were filled was 8.1 or 0.56 of 1 per cent more than the calculated gravity, the difference due to the loss of alcohol by evaporation, etc., being just about what experience shows was to be expected.

The yield can be calculated by analyzing the sample of beer due to be distilled and a sample of the slop. Determine the amount of alcohol in both samples, subtract the amount of alcohol left in the slop from the amount present in the beer, and the difference is the per cent of alcohol driven off as vapor to be condensed into spirit. Multiply this per cent of alcohol (by volume) by the number of gallons of beer and the quantity of alcohol distilled is obtained; multiply this result by 2 to obtain proof gallons. For instance:

	Per cent.
The alcohol in this beer was found to be	3.380
The alcohol in this slop was found to be	.090
There was therefore distilled from the beer	3.290

This fermenter held 2,135 gallons of beer, therefore 2,135× 3.290=70.24 gallons of pure alcohol. Multiply by 2 to obtain proof gallons, which equals 140.48 of spirits calculated. The actual yield from this tub was 145 proof gallons.

The correctness of this method has been tested by any number of analyses of quart samples taken at all stages of fermentation, and even as in the case cited above where the sampling is done under the most unfavorable circumstances the uncertain factor due to the loss by evaporation, etc., being largest, the results of the analysis agree with the actual yields to within 2 to 4 per cent.

Another example: A four-day test was made at a distillery mashing 3,000 bushels of grain a day, using 6 fermenters, 20,000 gallons of beer in each. Quart samples were taken from each fermenter with the following results:

	Calculated yield per bushel.	Reported yield per bushel.
	Gallons.	*Gallons.*
First day	5.11	5.05
Second day	5.037	5.129
Third day	5.012	5.047
Fourth day	5.127	5.091

This is but one of many tests made giving as good or better results.

The bureau laboratory is now being used, and will continue to be used, very extensively in verifying readings of distillery officers and in assisting distillery and examining officers in locating causes for any abnormal conditions that may be reported. The monthly reports of storekeepers giving the daily fermentation record of every tub or fermenter under their respective jurisdictions are subjected to the closest scrutiny in the new Division of Fermentology recently established in the bureau. Not only are the reports given careful scrutiny, but a complete and thorough system of checking up and verifying is being installed. If a distillery officer makes a report and fails to note any unusual or exceptional conditions obtaining in any tub on any day it will be supposed that the conditions were all normal and a conclusion will be reached and action will be instituted based on that supposition. If, therefore, there are any abnormal or unusual conditions the distillery officer must see that they are promptly reported at the time they are discovered, and that a proper reference to such a report is made on his Form 88 for the month.

Revenue agents, deputy collectors, and examining officers are expected to use every care in checking up distilleries and to render every assistance to distillery officers in the performance of their duty, and immediately report any incompetence, lack of intelligent effort, or irregularity on the part of any distillery officer, with a view to furthering the purpose of the bureau that there shall be collected for the Government every dollar of revenue due with the least possible annoyance or interruption in the business of the egitimate taxpaying manufacturer.

Form 88.

This form is a complete record of the operations of the distillery covered thereby, beginning with the grain weighed, then mashed, fermented, and distilled, thus enabling the distillery officers in charge to check a particular weight of grain throughout the entire process and measure the amount of alcohol produced therefrom.

Attention is called to the following points with respect to Form 88 which must be followed strictly by every United States distillery officer, and it is the duty of each and every visiting officer to see that these instructions are carefully and strictly obeyed:

1. Form 88 is to be prepared in duplicate and no excuse for an incorrect entry therein will be accepted. The entries are to be permanently made on each form immediately after the readings have been taken. If the readings are not permanently recorded before

the expiration of one hour after they have been taken the officer thus delinquent is liable to dismissal.

2. The data contained in Form 88 and Record 17 should of course be identical. Erasures should not, under any circumstances, be made in either Form 88 or Record 17. In event it is necessary to change an entry a light line should be drawn through the entry, the correct figures entered so as not to blur the original entry—red ink being used if convenient—and a notation made on the forms and records showing the time the alteration was made and the reason therefor. If any unusual conditions occur the same must be reported immediately in accordance with instructions on this subject and a notation relative thereto made at the time both on Record 17 and Form 88.

3. If the assignment of an officer whose duty it is to keep this form is changed during the month, the officer leaving must sign the form, noting the date of expiration of his assignment, leaving the form to be completed by his successor, by whom it must also be signed.

4. The method of taking and recording the gravity, as stated in T. D. 1750, must be followed. Any deviation from this method, unless authorized in writing by the commissioner, will be considered sufficient cause for the separation from the service of the officer responsible therefor.

5. Each column in Form 88 is to be filled in, or the reasons for the omission stated. Attention is called particularly to the "High or low wine" column, which is designed to show the amount of distillate in the first distillation. If only one distillation has been made, this fact should be written in this column. If two or more distillations are made, and if for any reasons the measurement of the first distillate can not be made, the reasons why must be clearly and concisely noted in this column of the form.

The time of distillation must be noted, when the distillation of the beer commences, and when the final distillation is complete. For instance, a certain house distills the beer one day and redistills the following day. The column would read: Tub No. 4—emptied June 11, at 9 a. m., distillation commenced June 11, at 10 a. m., distillation completed June 12, 4 p. m.

At the so-called "spirit" house the spirits are held so long in process of manufacture that the time of distillation completed can not be obtained. This column at such houses may be left blank, but the time of distillation commenced *must* be recorded as near as possible to the actual hour.

(T. D. 1750.)

Directions for taking gravity of distillery beer.

TREASURY DEPARTMENT,
OFFICE OF COMMISSIONER OF INTERNAL REVENUE,
Washington, D. C., January 19, 1912.

To collectors of internal revenue:

The following instructions are for storekeeper-gaugers in taking the gravity of mash and beer:

METHOD OF DETERMINING GRAVITY.

All mashes and beers are to be strained through a fine sieve or cheesecloth before making the determination.

Rye mashes *only*, at the time of filling, are to be diluted with water one to one after straining, and the gravity determined on the diluted sample.[a] After the beer is 24 hours old it is not to be diluted before making the determination.

The temperature of the *determination* is to be recorded in each case in the proper column.

Gravity is to be read to per cents and tenths.

Decimals are to be used in place of fractions.

Actual figures are to be recorded in each case; ditto marks are not to be used. Gravity is *not* to be corrected for temperature.

Distillers are to be required to furnish, at their own expense, accurate stems graduated to tenths, vessels in which to take the samples, sieves, and a cylinder or cup to hold the strained samples. (Revised Statutes, 3249–3303.)

ROYAL E. CABELL, *Commissioner.*

[a] Multiply reading by two to allow for the dilution.

Temperature corrections to saccharometer readings, standard at 60° F.

[Bureau of Standards, Nov. 23, 1911.]

Observed temperature.	Observed per cent of sugar.				
	0	5	10	15	20
	Subtract from observed per cent.				
°*F.* 50	0.1	0.2	0.2	0.2	0.3
52	.1	.1	.2	.2	.2
54	.1	.1	.1	.1	.1
56	.1	.1	.1	.1	.1
58	.0	.0	.0	.0	.1
	Add to observed per cent.				
60	0.0	0.0	0.0	0.0	0.0
62	.0	.0	.0	.0	.0
64	.1	.1	.1	.1	.1
66	.1	.1	.2	.2	.2
68	.2	.2	.2	.2	.2
70	.2	.3	.3	.3	.3
72	.3	.3	.3	.4	.4

Observed temperature.	Observed per cent of sugar.				
	0	5	10	15	20
	Add to observed per cent.				
°*F.* 74	0.4	0.4	0.4	0.4	0.5
76	.4	.4	.5	.5	.5
78	.5	.5	.5	.6	.6
80	.5	.6	.6	.6	.7
82	.6	.7	.7	.7	.8
84	.7	.7	.8	.8	.9
86	.8	.8	.8	.9	.9
88	.9	.9	.9	1.0	1.0
90	.9	1.0	1.0	1.1	1.1
92	1.0	1.1	1.1	1.2	1.2
94	1.1	1.2	1.2	1.2	1.3
96	1.2	1.2	1.3	1.3	1.4
98	1.3	1.3	1.4	1.4	1.5
100	1.4	1.4	1.5	1.5	1.6
102	1.5	1.5	1.6	1.6	1.7
104	1.6	1.6	1.7	1.7	1.8
106	1.7	1.7	1.8	1.8	1.9

GLOSSARY.

Balling.—Name of a standard saccharometer.

Beer.—Term for mash as soon as it enters the fermenter.

Bushel.—United States standard for distiller's grain—56 pounds.

Cooker.—Apparatus in which grain is mashed at high temperature—up to 309° F.

Diastase.—A substance present in malt capable of changing starch into sugar.

Doojum-pipe.—A pipe for the return of low wines (or condensed liquid of low proof) to still.

Doubler.—The still in which singlings are redistilled in making whisky; also the intermediate condensing vessel between the charge beer still and the condenser.

Dry inches.—Number of inches in fermenter between level of beer and top of tub (always to be expressed in actual figures not those of survey).

Fermentation.—The process by which a fermentable sugar is decomposed into alcohol and carbonic acid.

Gallon.—United States standard, 231 cubic inches of water at 60° F.; weight, 8.334 pounds.

High wines.—In South, redistillation distillate; in North, middle run of beer still distillate.

Low wines.—In South, distillate from beer still; in North, heads and tails of distillation.

Mash.—The liquid resulting from the mashing process.

Mashing.—The process (as applied to cereals) of mixing ground grain in water, dissolving the starch, and changing the starch to sugar.

Malt.—Grain which has been permitted to sprout for three or four days, forming diastase.

Saccharometer.—Instrument for determining per cent of sugar in a solution.

Singlings.—Beer still distillate.

Slop.—The liquid remaining after alcohol has been distilled from the beer.

Spent beer.—Same as slop.

Still:

- *Charge chamber*.—A still in which distillation is conducted in charges.
- *Continuous*.—A still the operation of which is continuous as long as the supply of beer lasts.
- *Pot*.—A simple still consisting of boiling chamber, gooseneck, and condenser.
- *Rectifying or column*.—A highly efficient type in which singlings are redistilled—about 60 to 80 per cent of product is alcohol of 190° proof.

Yeast.—Vegetable organism which produces alcohol as a product of fermentation.

○

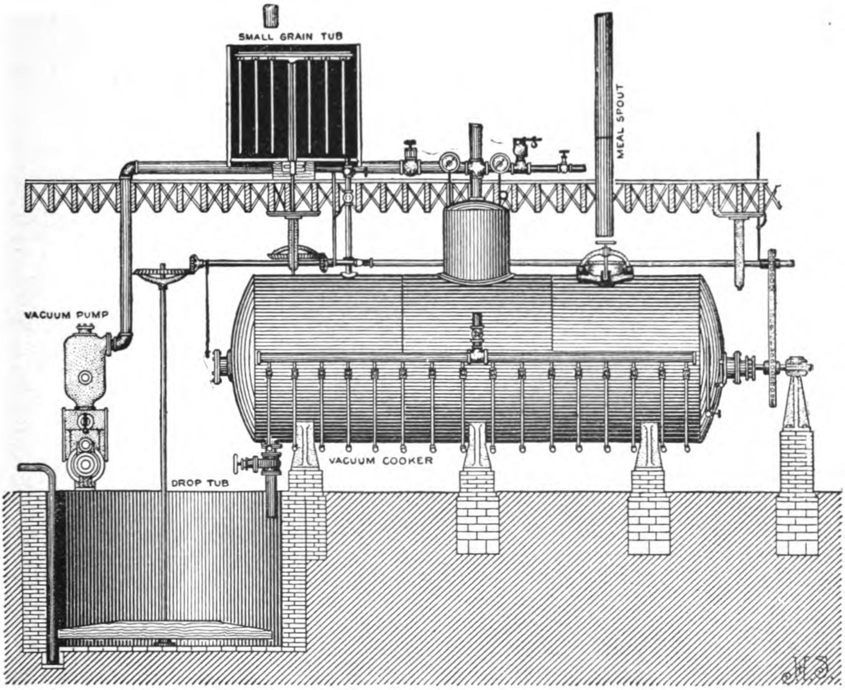

FIG. 1.—AMERICAN VACUUM COOKER.

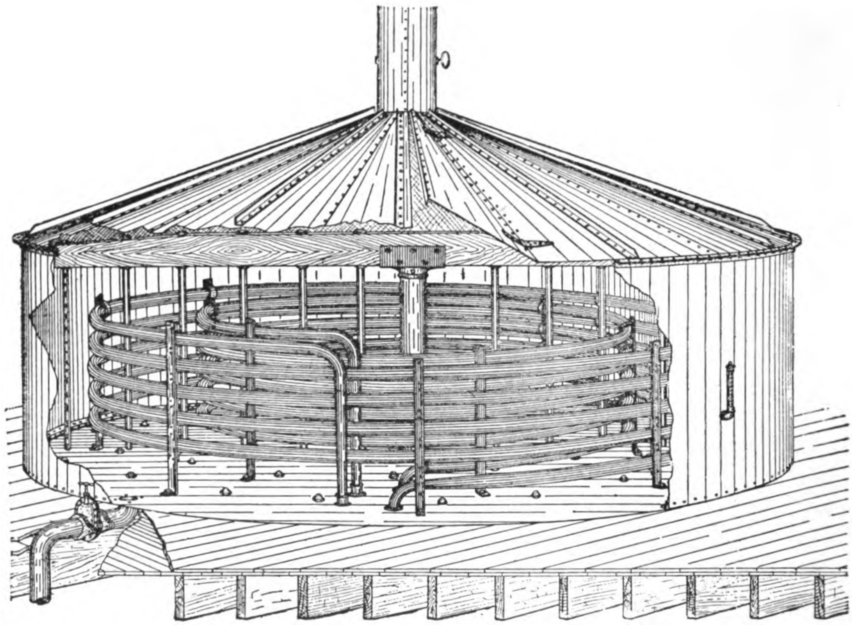

FIG 2.—OPEN MASH TUB.

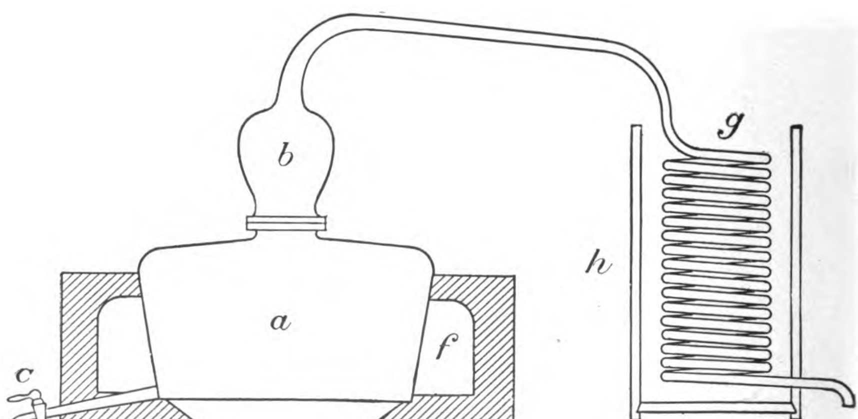

FIG. 3.—FIRE-POT STILL.

a, Kettle of still; *b*, head of still; *c*, draw-off cock; *d*, grate; *e*, masonry support; *f*, flue; *g*, condensing worm; *h*, worm tub.

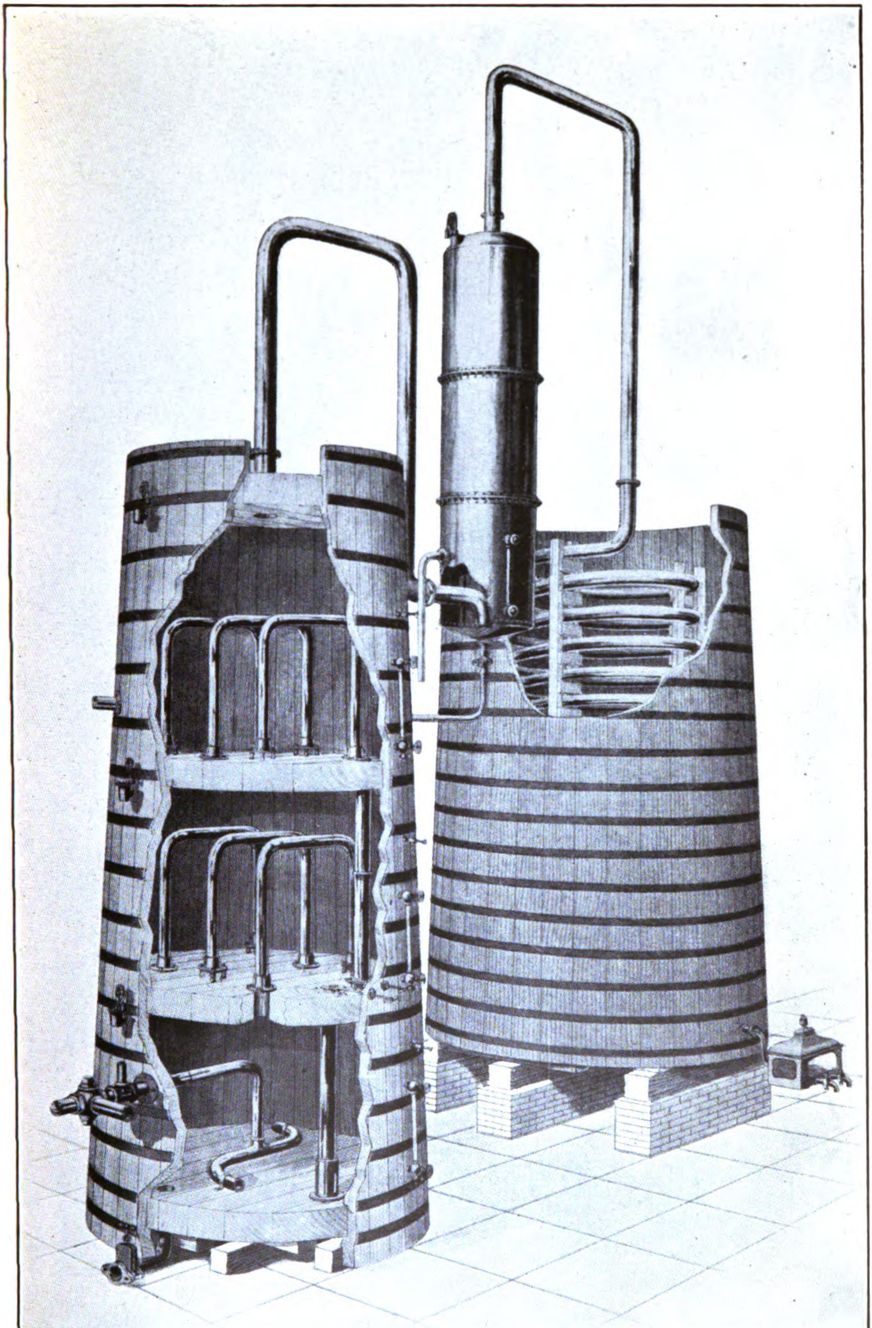

FIG. 4.—THREE-CHAMBER CHARGE BEER STILL.

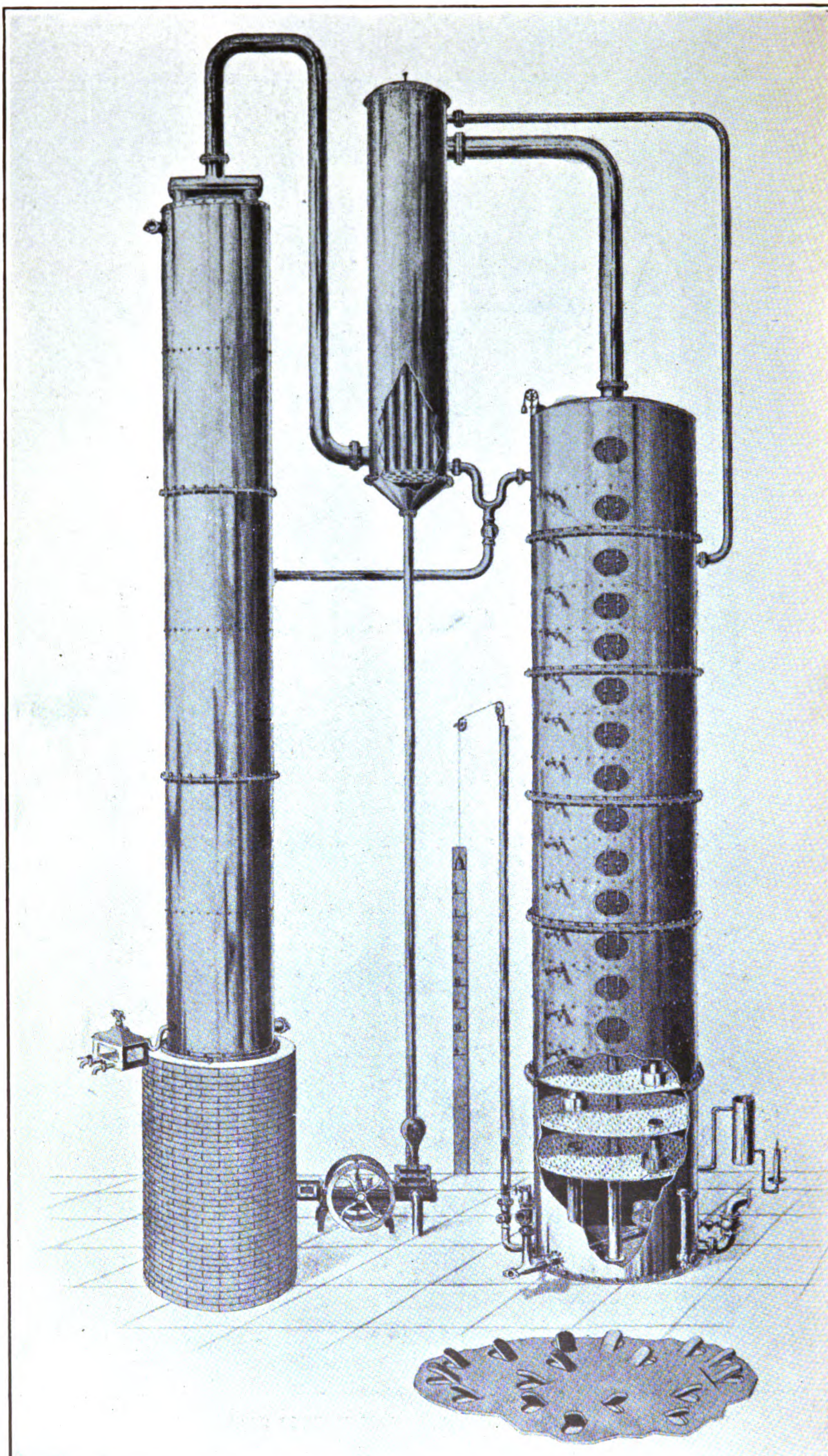

FIG. 5.—CONTINUOUS BEER STILL.

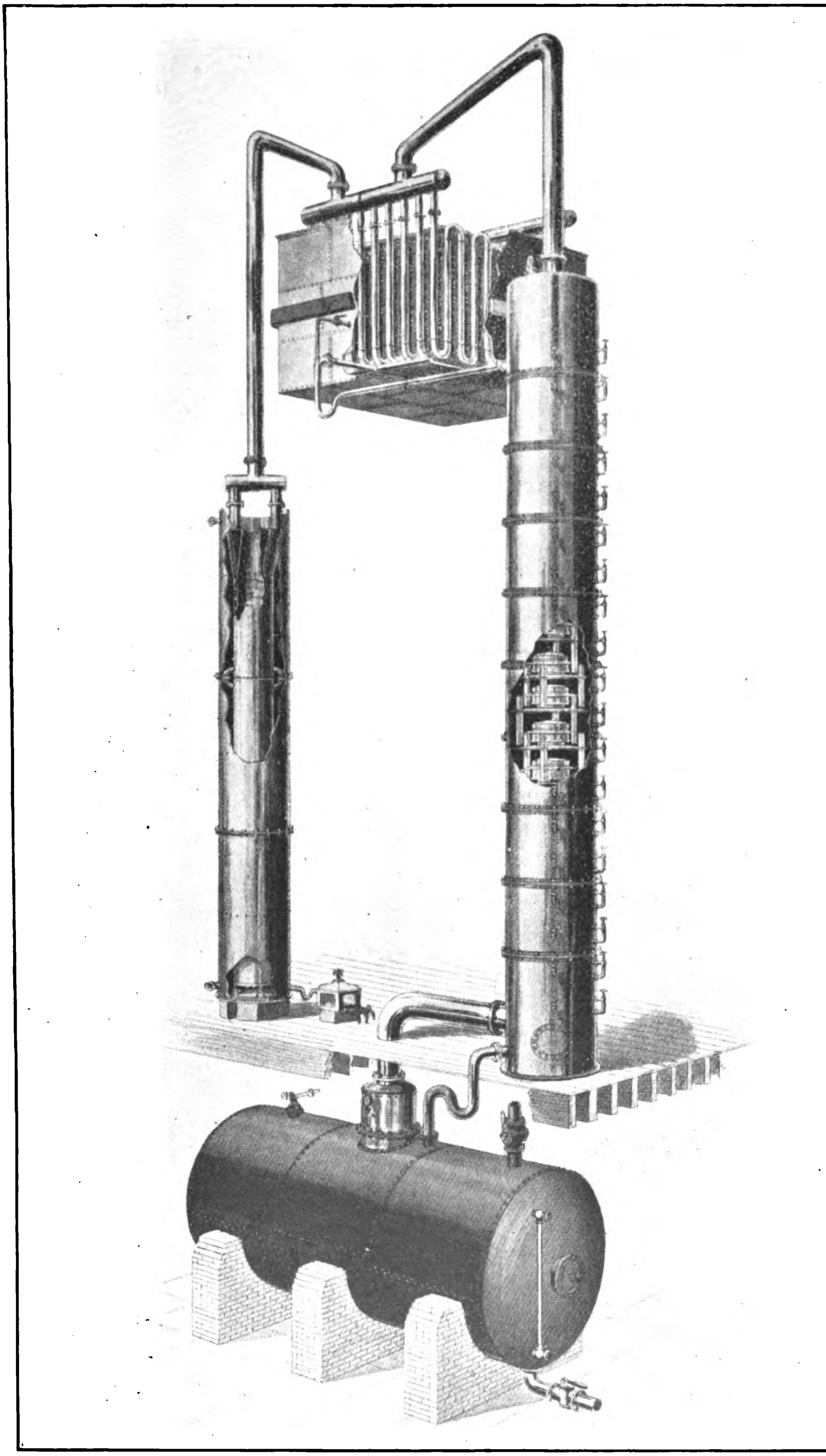

FIG. 6.—COLUMN STILL FOR ALCOHOL DISTILLATION.